Enabling ‘growth mindsets’ in engineering students

by

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Abstract

Student failure is often attributed to a lack of work by students. While this view has some merit, it implies that only students need to change and reduces the incentive for lecturers, curricula, assessment practices to be interrogated. In this thesis, I take a comprehensive look into *why* students do not work. Firstly, I place social psychology factors in context with other factors that impact student success and show how beliefs about academic ability underpin the academic behaviour that leads to success. By placing a learning theory lens on six characteristics of *fixed mindsets* (beliefs that ability can only be developed to an individually pre-determined level) and *growth mindsets* (beliefs that that effective effort will lead to unlimited self-improvement), I develop a theoretical framework that explains how both fixed and growth mindsets can be encouraged by teaching practices. As students with fixed mindsets may be more vulnerable to dropping out of university, lecturers should be aware of the mindset messages they are sending to students through their words, actions and choice of activities and assessment practices.

To address the question of *how* growth mindsets can be developed, I present results from a systematic literature review of growth mindset interventions aimed at engineering students, drawing on databases in education, engineering, and psychology. The findings show that most interventions involved informing students about mindsets and asking students to reflect on or teach others about mindsets, using personal examples. An intervention was devised to develop growth mindsets in engineering students through tutoring groups on the social media platform WhatsApp. Poor group functioning was addressed using a design-based research approach for the establishment of effective groups. Unexpectedly, assessments of engineering students’ mindsets through surveys and interviews showed very low numbers of students with fixed mindset views. Reasons for this result are explained by categorizing growth mindset enablers identified from literature and comparing the literature findings with interview data from engineering students. The thesis culminates by contributing a critique on mindset assessment and a framework for creating learning environments conducive to student success.

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Declaration

I confirm that I have been granted permission by the University of Cape Town's Doctoral Degrees Board and my co-authors, Tracy Craig, Brandon Collier-Reed, Inês Direito and Mashudu Mokhithi to include the following publications in my thesis. I confirm that the work presented is mine in concept and execution, with guidance from my supervisors and collaborators.

Signed by candidate

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List of additional publications and presentations

The following publication and presentations are relevant to the thesis, but not included:

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Campbell, A. L. (2019). Nudging lecturers towards promoting growth mindsets. *Regional Extended Curriculum Symposium: Best Practices in Extended or Foundation Programmes*, University of the Western Cape, 27 September 2019.

Campbell, A. L. (2019). An intervention to develop growth mindsets in engineering students at the University of Cape Town. *Research in Engineering Education Symposium* (REES). Cape Town, 10-12 July 2019.

Campbell, A. L. (2018). Why do top students fail at university? A puzzle piece from the social psychology theory of growth and fixed mindsets. *UCT Teaching and Learning Conference*. Cape Town, 11 July 2018. http://www.cilt.uct.ac.za/tlc2018-abstracts-alphabetical-author#10

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Contents

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Chapter 1: Introduction

1.1. Background to the study

Science and engineering graduates are crucial for stimulating innovation and new business in countries like South Africa that aim to transform to a knowledge-based economy (Reddy, Bhorat, Powell, Visser & Arends, 2016; Department of Higher Education and Training, 2014: 28; Blankley & Booysens, 2010). While some South African universities have approached the demand for more engineering graduates by increasing the number of first-year students, others have focussed on improving success rates before expanding first-year intake (Bokana, 2015). The strategy of increasing graduate numbers by increasing success rates requires institutions to understand and address the reasons why previously high achieving students fail when they enter university.

As universities grow larger and more diverse, the need for academic support is likely to grow. South African institutions also grapple with addressing the continued disadvantage from pre-1994 apartheid policies that deprived black African, Indian, Coloured and Chinese students of access to the same mathematics and science education provided to white students (Badat & Sayed, 2014; Park, 2009). Despite efforts aimed at addressing dropout, graduation rates at all South African universities have remained racially skewed with black African students having the lowest graduation rates (Council on Higher Education, 2013). Addressing reasons for failure by engineering students at the University of Cape Town would help to achieve the strategic plan of a 75% graduation rate (University of Cape Town, 2011).

In the 25 years that I have tutored and lectured first-year mathematics students, I have seen how student success can be positively influenced by well-structured courses, inspirational teaching, carefully designed assessments, financial support and social support. However, even when these features appear to be in place, I have seen how many students still do not succeed. On the other hand, some students achieve academic success while enduring very difficult academic, socio-psychological and environmental circumstances (Mogashana, 2015). I suggest that poor performance often follows inappropriate student behaviour, for example missing lectures, completing work at the last minute, prematurely giving up on challenging problems, not reviewing mistakes made in assessments, not working in a study group and adopting a surface approach to learning (Entwistle & Ramsden, 2015) rather than a deep or even a strategic approach to learning. Interactions with students have revealed to me that many students are aware of the behaviour that I suggest would support their learning goals but fail to put the behaviour into practice. To help students, I found that I needed to understand more about the reasons for their behaviour choices.

Psychology research demonstrates the complexity around making behaviour changes, and the strong influence of attitudes and beliefs on behaviour choices (Bandura, 1977; Conner & Armitage, 1998; Ajzen & Fishbein, 2005). In particular, research on students' beliefs about their academic ability, termed 'mindsets' (Dweck, 2006) provided an explanation for what I was observing in students with a history of high achievement who were now facing academic challenges.

I found that the potential for mindset theory to impact academic success had led to large-scale mindset development for teachers and students, including through online courses (Anderson, 2019a; Boaler, Dieckmann, Pérez-Núñez, Sun & Williams, 2018; PERTS Mindset Kit, 2020; Mindset Works, 2017; YouCubed, n.d.), books (Brock & Hundley, 2017; Boaler, 2015) and many academic publications (see meta-analyses by Costa & Faria, 2018; Sisk, Burgoyne, Sun, Butler & Macnamara, 2018; Sarrasin et al., 2018). Most mindset development was targeted at primary school students and teachers to maximise the potential benefits on students' lives. Students' mindsets were found to be especially influential in challenging times, such as the transition to high school or to university.

Another significant influence on the behaviour of university students is the central role that mobile devices play in most of their lives (Chuma, 2014). An estimated 95% of students globally own a mobile device (Alexander et al., 2019), even in low-income communities where devices are often shared (Rivera-Sánchez & Walton, 2013). Furthermore, widespread mobile internet connectivity is changing how learning happens (Ng'ambi et al., 2015). Mobile devices offer interesting possibilities for future directions in education, including interventions to develop mindsets linked to academic success.

This thesis addresses a knowledge gap around the application of social psychology in university engineering education for the purpose of improving student success, particularly through interventions that may include mobile devices.

1.2. Statement of the problem

Mindsets (beliefs about academic ability) influence behaviour which in turn influences academic success. While there is research evidence that using social psychology theories such as mindsets (Dweck, 2006) can promote student success (Yeager at al., 2019; Costa & Faria, 2018), it is unclear *how* a tertiary-level educator of engineering students could effectively use social psychology theories to improve their students' success. Interpreting research on mindset development is complicated by inconsistencies in how mindsets are assessed. Furthermore, beliefs can be slow to change. For example, Dringenberg and Kramer (2019) found that even after a semester-long intervention involving five hour-long discussion sessions on the book *Mindset* (Dweck, 2006), some persistent misconceptions about mindsets remained in the participating first-year engineering students.

In many countries, including South Africa, where this study is based, acceptance to study engineering at university is very competitive and many top school achievers enrol with the intention of becoming engineers. It seems incongruous that so many engineering students drop out due to poor academic performance. Degree completion rates for engineering have remained low despite wide-ranging interventions to improve them (Department of Higher Education and Training, 2019; Shay, 2017). Integrating social psychology theories into strategies to improve student success in engineering education may help improve academic success. The benefits of incorporating social psychology theories may extend beyond academic performance to mental health. As mental health is a leading health issue affecting as much as one in four people globally (Vos et al. 2016; United Nations, 2015), interventions that strengthen mental health in students are important. However, the application of social psychology theories in engineering education is a relatively new area of research and there is little theoretical research into how social psychology theories relate to learning theories, or what conclusions can be drawn from social psychology interventions aimed at engineering students. Research-based guidelines for educators would help to move research into practice.

1.3. Purpose of the study

The overarching purpose of this thesis is to provide theory-based support for educators who want to develop growth mindsets in their engineering students.

The first new contribution to existing literature made in this thesis is a theoretical framework showing how fixed and growth mindsets relate to the four learning theories of behaviourism, constructivism, communities of practice and connectivism, and how activities based in each of these learning theories can support either fixed mindsets or growth mindsets. The implication of this theoretical contribution is that educators may unknowingly be encouraging either a fixed mindset or a growth mindset in students. Since students with growth mindsets more readily take on challenges, persevere when faced with difficulties, put more effort into activities, and make better team members than students with fixed mindsets, educators should aim to develop growth mindsets rather than fixed mindsets in their students. The framework provides examples to guide educational practices based in any of the four considered learning theories.

Secondly, this thesis provides a review and synthesis of intervention studies aimed at developing growth mindsets in engineering students. A systematic literature review draws on databases of studies from the fields of education, engineering and psychology to provide inspiration and guidance for educators wishing to design focussed growth mindset interventions to suit their students and contexts. The literature review also shows that assessing mindsets is complicated by the wide range of types of mindset scales used.

Thirdly, a contribution to international mindset literature is made through analysing mindset assessments of 265 first-year engineering students at a South African university, both quantitatively using an existing Likert-style mindset scale, and qualitatively using interview data from 17 students. The challenges and limitations of mindset interventions and mindset assessment are further elaborated with reference to social psychology literature.

Drawing on the findings of the literature review, a mindset intervention was devised that would use a tutoring system on a social media platform. Design-based research over three years was applied to develop principles for setting up such a tutoring system that could be used to develop growth mindsets in peer tutors. Participants in the design-based research were engineering students who were tutors, their high school tutees and researchers. The resulting design principles can also be applied to tutoring systems set up for purposes other than mindset interventions and provide a fourth addition to research literature.

Finally, a comparison is made of literature-sourced experiences that enable growth mindsets with experiences that first-year engineering students recall from school and their first-year at university. The results give insight into how growth mindsets are formed through the experiences of students at a South African university.

The central purpose of the thesis is to argue that growth mindset interventions need to focus on developing mindsets in learning environments and not just in individuals. Examples from literature are compiled to suggest how to create learning spaces that support growth mindset development.

1.4. Research questions

The primary research question addressed in this thesis is:

> *How can growth mindsets be developed in engineering students?*

The secondary research questions are addressed in chapters two to six:

1. How are behaviours associated with growth mindset and fixed mindsets viewed through different learning theories? *(Chapter two)*
2. How effective are different interventions to develop growth mindset in engineering students? *(Chapter three)*
3. What measures have been used in assessing the effectiveness of mindset interventions? *(Chapter three)*
4. Who benefited from these interventions, in terms of gender and year of study? *(Chapter three)*
5. What design principles can guide the establishment and operation of peer tutoring groups on a social media platform? *(Chapter four)*
6. How do students' beliefs about academic ability in university mathematics shift in their first year of university? *(Chapter five)*
7. How can social psychology theories explain why it is difficult to implement mindset interventions and to get an accurate assessment of mindset? *(Chapter six)*
8. What can be identified from growth mindset literature as experiences that promote the development of growth mindsets? *(Chapter six)*

9. Which experiences that develop growth mindsets do first-year students recall from their school and first-year experience? *(Chapter six)*

1.5. Structure of the thesis

Chapters two to six are presented as journal articles, prefaced with an introduction and concluded with a reflection that links the article to the flow of the central thesis objective, which is to explore how growth mindsets can be developed in engineering students. The end of chapter six includes a final reflection that draws together the arguments made to that point. Specific objectives for each chapter are provided below.

Chapter 1: Introduction. The need to improve the success of engineering students is motivated with statistics of low graduation rates in South African universities. Mindset theory, a social psychological factor, is shown to be a promising field of research for improving student success. Knowledge gaps are identified, and research aims and questions are outlined.

Chapter 2: Theoretical framework. The aim of this chapter is to develop a framework that shows how behaviours associated with growth and fixed mindsets can be viewed through the perspectives of different learning theories. The conclusion is that educators should be aware of the mindset messages they may be inadvertently sending as fixed mindset students may be more vulnerable to dropping out.

Chapter 3: Literature review. Large-scale studies and meta-analyses have established that growth mindsets are associated with greater student success than fixed mindsets. Less is known about how to develop growth mindsets, particularly in post-school settings. The results from this systematic literature review show that the most common intervention method for developing engineering students' mindsets was to share mindset information with students and then have students share their reflections or advice with other students.

Chapter 4: Design-based research. An intervention to develop growth mindsets was designed in which engineering students who were volunteer tutors would be told about mindsets in a face-to-face meeting and with existing videos. Tutors would be encouraged to share what they had learnt with tutees. The operation of the tutoring groups on the social media platform WhatsApp was initially weak. The functioning of the tutoring groups was refined using design-based research.

Chapter 5: Assessment of mindsets. To test the effectiveness of a growth mindset intervention, we need to be able to assess students' mindsets. A standard, eight-item Likert-style mindset survey returned the surprising result that only 7% of the 265 engineering students surveyed had fixed mindsets. Interviews with 16 students provided an additional measure of mindset. A close-up assessment of students showed that small shifts towards growth mindsets were made during their first year. Potential reinforcers of fixed mindsets are discussed.

Chapter 6: Mindset interventions must target learning environments, not just students. To better understand why very few engineering students were assessed to have fixed mindsets, literature-based experiences that enable growth mindsets were summarised and compared to interview data from first-year engineering students. Discrepancies between the literature and interview responses were found, adding insight into how growth mindsets develop in South African first-year university students. Exploring the contributions from social psychology research to problems with mindset interventions and mindset assessment led to the central contribution of the thesis: Heslin, Keating and Ashford's (2019) theory of dual-model of mindsets as *dispositional* (reflecting beliefs about who you fundamentally are and what you are or are not capable of), or *deliberate* (able to be invoked) supports the argument that growth mindset interventions need to focus on developing mindsets in learning environments and not just in individuals.

Chapter 2: Theoretical framework

2.1. Chapter introduction

As discussed in the introduction chapter, I felt that Dweck's (2006) theory of fixed and growth mindsets was relevant to my goal of helping engineering students reach their goal of graduating. I wanted to know how the learning theories that educators use to guide their teaching practice could affect the fixed or growth mindset messages they might be indirectly sending to students through their choice of learning activities. Broadening my understanding of the connection between learning theories and mindsets would fill a gap in the literature and guide the direction of my study into developing growth mindsets in engineering students. This chapter considers the secondary research question, *How are behaviours associated with growth mindset and fixed mindsets viewed through different learning theories?*

This chapter is presented as a published journal article, for which the reference is:

Campbell, A. L., Craig, T. S., & Collier-Reed, B. (2020). A framework for using learning theories to inform 'growth mindset' activities. *International Journal of Mathematical Education in Science and Technology*, 51(1), 26–43. https://doi.org/10.1080/0020739X.2018.1562118

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2.2. Abstract

Social psychology research confirms that learning can be influenced by what students believe about their academic ability. Students with a 'growth mindset' believe academic ability can increase with appropriate effort and are more likely to persevere following setbacks, embrace challenges and ask questions. In contrast, students with a 'fixed mindset' believe academic ability is inherent, that beyond a basic level you are not able to do much to change your academic ability. Fixed mindset beliefs are linked to behaviours that that can lead to the avoiding of challenges and reduced learning, such as concealing a lack of understanding to retain an image of being 'smart'. The fixed and growth mindset theory offers a possible reason for observed underachievement in

science, technology, engineering and mathematics (STEM), particularly for students who have previously excelled in these disciplines.

The potential impact of a growth mindset on STEM achievement, particularly for minority and low-household-income students, has resulted in calls to develop interventions that encourage growth mindsets and discourage fixed mindsets. However, interventions in an education context are influenced by the developer's understanding of how learning occurs. A framework to show how activities based on different learning theories may encourage growth mindsets or (unintentionally) encourage fixed mindsets can guide the developers of growth mindset interventions.

We present such a framework in six tables relating to key areas associated with growth and fixed mindsets: dealing with challenges, persistence, effort, praise, the success of others and learning goals. Each table gives examples of learning activities that may encourage growth or fixed mindsets, fitting with each of four key learning theories: behaviourism, constructivism, communities of practice and connectivism.

Keywords: Learning design; Dweck; beliefs; behaviour; mindset.

2.3. Self-beliefs and behaviour change

For most students, a necessary (but not sufficient) condition for academic success is appropriate academic behaviour, such as reviewing errors made in tests (Ambrose, Bridges, DiPietro, Lovett, & Norman, 2010). In many cases, if a student fails an assessment, it is an indication that a change in their behaviour is necessary. However, realising that one's behaviour should change is often not enough to cause a lasting change in behaviour. Behaviour change theory suggests that behaviour is strongly linked to beliefs (Schoenfeld, 1989), as described in Figure 2.1. Lasting behaviour change would therefore appear to require a change in the self-beliefs that underpin the behaviour.

Figure 2.1: The relationship between self-beliefs, behaviour and success

The next two sections describe behaviours associated with academic success and how these behaviours may be affected by self-beliefs.

2.3.1. What are the behaviours associated with academic success?

From the many studies that have classified academic success factors (for example Ambrose et al., 2010; Muse, 2003; Sparkman, Maulding, & Roberts, 2012), three main groups can be distinguished: (1) teaching and learning factors, (2) environmental factors, and (3) socio-psychological factors, as shown in Figure 2.2. Examples of behaviours relating to teaching and learning are working collaboratively in groups (Johnson, Johnson, & Stanne, 2000), accessing prerequisite knowledge (Craig & Campbell, 2013) and engaging in active learning in class (Michael, 2006). Behaviour relating to environmental factors include managing personal finance (Johnson, Rochkind, Ott, & Dupont, 2009), using appropriate working space (Waldock, Rowlett, Cornock, Robinson, & Bartholomew, 2015) and participating in living-learning communities (Tinto, 2003). Socio-psychological factors include a range of self-beliefs that affect students' performance in learning activities and assessments (Farrington, 2013), such as beliefs about academic ability (Dweck, 2006), self-efficacy (Bandura, 1977) and stereotype threat (Spencer, Steele, & Quinn, 1999).

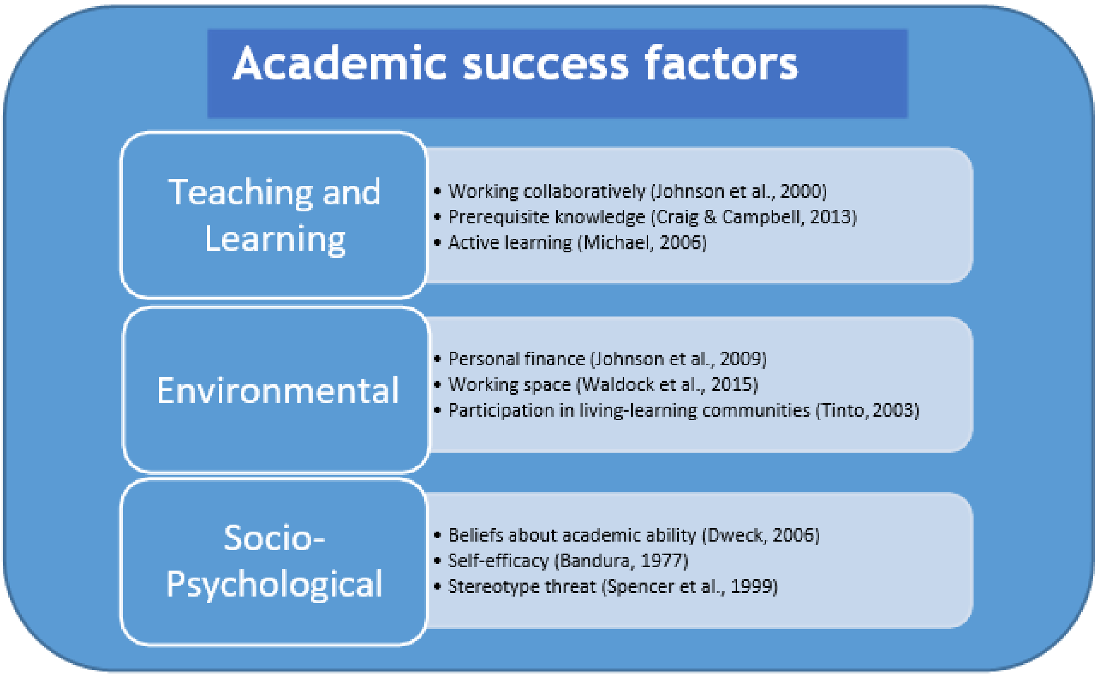

Figure 2.2: Classification of factors affecting academic success, with examples

2.3.2. How are the behaviours important to academic success affected by self-beliefs?

Self-beliefs or self-theories (Dweck, 2000) are people's beliefs about their personal attributes. Examples of self-beliefs are motivation (Pintrich, 2003), alienation (Mann, 2001) and 'grit,' the determination to achieve long-term goals (Duckworth & Gross, 2014).

Self-beliefs about abilities matter most when people face difficulties (Dweck & Grant, 2008), such as in the transition to a new educational institution, or when students with a history of high achievement in mathematics fail a mathematics test. Apart from affecting quality of life (Bandura, 2004), the self-beliefs people hold affect their motivation and consequent achievement. Dweck and Grant (2008) describe the link between self-beliefs and achievement in three phases, which we have depicted in Figure 2.3:

- Self-beliefs foster goals;
- Self-beliefs and goals foster helpless versus mastery-oriented reactions; and

- Helpless versus mastery-oriented reactions predict self-esteem and academic success.

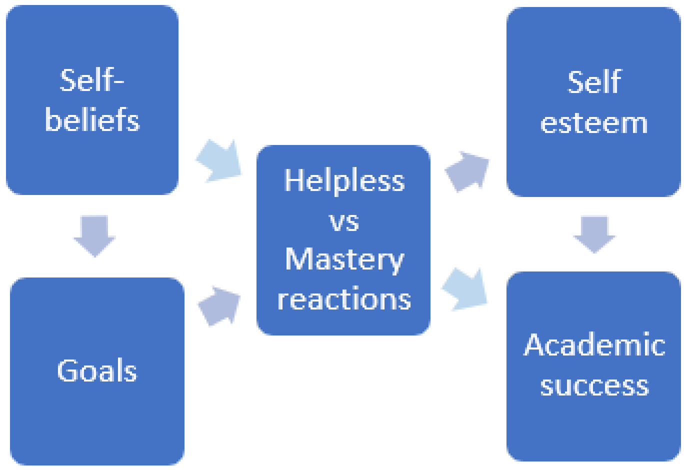

Figure 2.3: The expanded relationship between self-beliefs, behaviour and success

2.3.3. Academic ability self-beliefs

Since the early 2000s, there has been growing research interest in the opposing self-beliefs about academic ability as either a fixed trait that you cannot do much to change - a 'fixed mindset' - or something you can develop - a 'growth mindset' (Dweck, 2006). Meta-analyses by Burnette, O'Boyle, VanEpps, Pollack, & Finkel (2013) and Valentine, DuBois and Cooper (2004) support that people with growth mindsets are more likely to display behaviour that leads to academic success, such as asking questions, persisting when faced with challenging problems or acting on constructive feedback.

Fixed beliefs about intelligence may explain why some students who were previously high achievers are not able to overcome the setback of failing. Some students can describe the actions they should take to be more successful, for example attend class, plan study time, ask for help when stuck, work in study groups, but they fail to implement these actions even though they also express a strong desire achieve a degree, and recognise that these actions are essential to this goal.

Table 2.1 lists typical growth or fixed mindset behaviour. The first five behaviour categories, namely dealing with challenges, persistence, effort, praise and the success of others, are summarised in Dweck (2006). The sixth category, learning goals, has been included for its links to academic tenacity (Dweck, Walton, & Cohen, 2014). Growth mindsets are associated with deeper learning (Farrington, 2013) and being able to develop competence in a topic. Fixed mindsets devalue learning from mistakes since a judgement of ability has already been made.

Table 2.1: Behaviours characteristic of growth mindsets and fixed mindsets (expanded from Dweck, 2006)

Category	**A growth mindset person will …**	**A fixed mindset person will …**
Challenges	**Choose or value challenges** that will lead to more learning. "I like a challenge."	**Avoid challenges** that may expose areas of weakness. "I like things I know I can do well."
Persistence	**Persist** after setbacks, show resilience. "I'll have to try harder or work differently."	**Give up easily** after setbacks, or become defensive, or helpless. "What's the point in trying? I don't have what it takes to succeed."
Effort	**Put effort into academic work.** "Worthwhile learning usually requires hard work."	**Avoid appearing to work hard** as it suggests low ability. "Learning should be easy if you are intelligent."
Praise	Give or value **praise for effort** over praise for talent. "Well done, great work."	Give or value **praise for talent** rather than effort. "You're a star, you're a winner, you're a top student."
Success of others	Learn from and feel **inspired by the success of others**. "I can try that."	Feel **threatened by the success of others**. "Will they make it harder for me to be seen as successful?"
Learning goals	See the **goal of learning** as **improving performance**. "What can I learn from the mistakes I made in the test?"	See the **goal of learning** as **showcasing performance**. "High performance in a test shows that I am learning."

Much of the research on academic ability beliefs has been at school level (Kearney, 2015) but university-level research (for example Wiersema, Licklider, Thompson, Hendrich, & Haynes, 2015; Yan, Thai, & Bjork, 2014; Stump, Husman, & Corby, 2014) points to the value of developing growth mindsets in higher education students too. Paunesku et al. (2015) suggest the possibility of making significant improvement to education on a large scale through interventions that develop growth mindsets. Meta-analyses caution against expecting significant change in academic achievement simply by developing growth mindsets but noted that growth mindset interventions do have significant effects on academic achievement for academically high-risk and low-income students (Sisk et al., 2018).

While there is a growing body of literature around developing growth mindsets, there is limited theory-linked advice for people wanting to develop their own growth mindset interventions to improve the academic success of university students. We argue that an important consideration for designing growth mindset interventions is the context in which the intervention takes place. A context where learning is seen as the acquisition of knowledge is likely to have a different set of success-related behaviours compared to a context where learning is seen as the production of knowledge within a community. The aim of this paper is to develop a framework that shows how behaviours associated with growth and fixed mindsets can be viewed through the perspectives of different learning theories. The framework is presented as a series of tables and includes examples to show how activities based on different learning theories may encourage growth mindsets or (unintentionally) encourage fixed mindsets.

Before we present the framework, we discuss and summarise four learning theories – behaviourism, constructivism, communities of practice and connectivism.

2.4. Theories of learning

We suggest that it is deeply held (rather than academically professed) theories of learning that drive the design of our learning activities. We agree with Begg (2011) that learning theories do not provide 'the truth' about how learning happens but provide insight into how learning happens. So, similar to how an understanding of different sports can help us choose what to play to achieve specific fitness goals, a knowledge of learning theories can help us choose learning activities to achieve learning goals. It is possible to use different theories of learning in combination. Examining the alignment of our learning theories with our learning goals should help us design activities to develop growth mindsets that are more robust and effective than if designed only from intuition.

Harasim's (2012) grouping of learning theories by epistemological differences – the way we know things – distinguishes between *objectivist theories* that take knowledge to be absolute and match with reality, and *constructivist theories* that regard knowledge as created to fit with reality. Others (for example Sfard, 1998; Case, 2008) have used the terms acquisitionist and participationist to describe theories that see learning as the process of acquiring objective knowledge (acquisitionist) or as the production of knowledge within a learning community (participationist). The summary that follows considers four dominant learning theories through their historical development.

2.4.1. Learning as acquiring objective knowledge: Behaviourism

An early major learning theory, behaviourism, was based on animal behaviour research by stimulus-response psychology researchers (Skinner, 1963). Three guiding principles are that human behaviour can be understood by objective analysis, that environmental impacts on human behaviour can be complex and subtle, and that future behaviour can be shaped with reinforcement (Ertmer & Newby, 1993). Despite the shortcomings of behaviourism (for example Cooper, 1993), it underpins many computerised learning approaches that use practice, repetition and feedback to reinforce memory associations, for example, mastery quizzes and counting drills. However, this theory did not engage with how the mind influences learning, why people who experience the same teaching do not all learn the same content equally, or why humans do not always respond to stimuli in the same ways (Stewart, 2012). Questions about the impact of social behaviour and objections to the behaviourist view of learners as 'empty vessels to be filled' with knowledge led to the development of one of the most widely referenced learning theories to date, constructivism (von Glasersfeld, 1983; Fosnot, 2005).

2.4.2. Learning as producing knowledge within a community: Constructivism, Communities of Practice, Connectivism

In contrast to theories based on an understanding of knowledge as absolute and objective, the following learning theories emerge from a *constructivist epistemology*, where knowledge is viewed as subjectively created by learners to fit with how they perceive reality.

Constructivism

The central claim in constructivism is that learners "construct" new knowledge based on prior learning. Interaction with more knowledgeable teachers or peers shapes learners' perceptions, which in turn shapes knowledge construction. The teacher is a "director" of knowledge construction rather than the knowledge-giver.

Constructivist teaching approaches include active learning (Prince, 2004), learning-by-doing (Gibbs, 1998/2013), scaffolded learning (van de Pol, Volman, & Beishuizen, 2010), creating cognitive conflict (McCormick & Scherer, 2018) or by using reflective writing (Craig, 2016), and externalising memory on lists and concept maps to favour relationships and content over recall (Zhang & Norman, 1994).

Sociocultural theories of learning shifted from the early constructivist focus on individual cognitive development (Piaget, 1955) to a focus on what conditions make learning possible, where learning is the enculturation into existing practices (Cobb, 1994). In his posthumously-published collected works, Vygotsky (1978) captures the value of teachers, who could be peers, by defining the 'zone of proximal development' as

> *"...the distance between the actual developmental level as determined through independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers." (p. 86)*

Teaching strategies aligned to sociocultural learning theories include reviewing exam questions using samples of students' errors, group work, and formative assessment that guides the instructor on the current knowledge state of the learners (Hassan, 2011).

More recent sociocultural theories of learning have highlighted the development of student identity as an essential part of the learning process (Allie et al., 2009) and accounted for the influence of the environment as well as other people (Doolittle, 2014). Interactions with others are the basis in theories such as the influential theory of communities of practice.

Communities of Practice

Communities of practice is a theory of social learning founded on observations of apprenticeship learning (Lave & Wenger, 1991). It directs education developers to consider the activity, culture and context in which learning takes place. A community of practice forms when group members connected by a concern or passion for an activity learn to do the activity better through regular interactions (Wenger, 1998). Learning may or may not be intentional. Through observation, apprenticeships, and 'legitimate peripheral participation,' newcomers can become core participants, recognised by the community as experts. Lave's (1988) claim that knowledge needs an authentic context and a structure suggests the use of learning activities such as site visits, guest lecturers and real-life data statistics. Participants gain social capital (Bourdieu, 1991) as they gain knowledge and acknowledgment from their peers. Peer tutoring (Boud, Cohen, & Sampson, 1999; Topping, 2005), displaying examples of students' work (Webb, 2009) and guided peer marking (Falchikov & Goldfinch, 2000) are activities that place students in more central roles in the community of practice.

Connectivism

Internet-connected devices have enabled personal interactions between people and information at a scale that connectivism developers (Siemens, 2005; Downes, 2007) argue is changing learning beyond the explanations available from previous learning theories. Taking a strong participationist view that learning is participation rather than the by-product of participation, connectivist learning is the construction and use of networks of connections between human and non-human information resources or 'nodes' at three levels: the cognitive, concept, and social. However, unlike the constructivist concept of knowledge as individually constructed, in connectivism "there is no real concept of transferring knowledge, making knowledge, or building knowledge" (Downes, 2007, para. 7). Networks of individuals and groups are developed through the meaningful incorporation of information gathered from interactions with resources. Learning follows from activating learner participation (supported by technology) resulting in the formation of cognitive, concept or social networks.

Connectivist learning activities should expand the learning networks of students. Activities include accessing, critically evaluating and synthesising diverse information resources, and contributing self-generated content through blogs, videos and comments.

2.5. A framework of growth and fixed mindset behaviour viewed through different learning theories

We do not see learning theories as restricting educators to identify most strongly with one theory that they use exclusively. While this may happen, it is more likely that different circumstances call for different approaches based in different theories. For example, behaviourist drill-and-practice with feedback can prepare students for a connectivist activity of identifying and explaining in a video the errors from anonymised work of peers from another school. Growth or fixed mindsets could be encouraged within each activity. For example, a ranking board of the drill-and-practice results with rewards for top achievers may encourage fixed mindsets, whereas feedback showing where to find more resources to improve may encourage growth mindsets.

The tables below explore the six behaviour categories from Table 2.1 – challenges, persistence, effort, praise, success of others and learning goals - in relation to the four learning theories of behaviourism, constructivism, communities of practice and connectivism. Examples are suggested for activities aligned to each learning theory that may be used to encourage growth or fixed mindsets.

2.5.1. Challenges

A growth mindset response to a challenging task is eagerness to learn. A fixed mindset response to a task which may display areas of weakness is avoidance or self-sabotage, so that a poor outcome may be blamed on not enough effort rather than not enough ability.

Table 2.2: How challenges relate to learning theories and mindsets

Learning theories	How challenges relate to each learning theory	Growth mindset: How can valuing challenges be encouraged?	Fixed mindset: How can avoiding challenges be (unintentionally) encouraged?
Behaviourism	Success with challenges should follow from observation of an expert solving challenging problems and practice with similar types of problems.	Give smaller rewards for easy problems and greater rewards for challenging problems. Minimise negative consequences for mistakes. Allow self-paced video viewing and multiple quiz attempts until success with a challenge has been achieved.	Strong negative feedback (for example public humiliation, a shocking noise) may invoke such negative emotion that a learner avoids future engagement with similarly challenging learning activities.

Constructivism	Success with challenges should follow from sufficient scaffolding to keep the level of challenge within an achievable 'zone of proximal development.'	Use a wide selection of resources, with challenging and more basic options. Give credit for the use of questions when stuck. Model how asking questions can lead to progress when facing a challenge. Ask students to set challenging problems and mark peers' attempts at answering them.	Fixed mindsets may be reinforced if a learner is concerned that they consistently receive more support than their peers, or that they need support that their peers do not need when challenged. They may disengage rather than have the differences between them and their peers validated.
Communities of practice	More central members of the community of practice are more likely to be able to resolve challenges and can advise novice apprentices.	Have experts explain how they dealt with challenges and how their failures led to learning.	Core members of a community of practice (e.g. teachers, older peers) may role model challenge-avoidance to less experienced members. Experts may forget their earlier struggles and talk of challenging work being easy.
Connectivism	Challenges can be resolved by connecting to information resources (e.g. people, videos).	Favour resources that include more complex problems, explanations of common mistakes and the use of a variety of methods of solving problems in the topic. Model help-seeking behaviour so it is not seen as a sign of weakness but natural behaviour	Fixed mindsets could be reinforced if students fail to find or make sense of the information resources in their networks, especially if they perceive that peers are not similarly challenged.

		that leads to increased learning.	

2.5.2. Persistence

Having received unfavourable feedback on a task performed at a low level, a growth mindset response is to look for ways to improve while a fixed mindset response to unfavourable feedback is to withdraw, give up or blame circumstances. Favourable feedback may cause complacency in someone holding a fixed mindset but not in someone holding a growth mindset.

Table 2.3: How persistence relates to learning theories and mindsets

Learning theories	**How persistence relates to each learning theory**	**Growth mindset: How can persistence after setbacks be encouraged?**	**Fixed mindset: How can giving up easily be (unintentionally) encouraged?**
Behaviourism	Persistence means responding to feedback (in the form of positive or negative reinforcement or punishment) by adjusting behaviour and more practice with feedback.	Feedback on low achievement should emphasise that improvement is possible, suggest alternative strategies and allow repeated attempts.	Feedback such as public display of ranking or low scores may encourage giving up, especially if the feedback creates shame and there are no opportunities to improve.
Constructivism	A persistent student continues to learn through constructing individual meaning from input by someone more advanced.	Offer scaffolded activities that are not too far beyond a learner's current state of knowledge, and more opportunities to recover from failure. Give links to resources where prerequisite content may be found. Give partial credit for failed attempts that	Repeated attempts at assessments too far beyond a student's current ability may bring further setbacks and confirm beliefs that "I don't have what it takes."

		follow problem solving steps.	
Communities of practice	A persistent student interacts regularly with a community of practice and this leads to a more central role in the community.	Inspirational stories of core community members who persisted after setbacks provide role-modelling and encouragement.	If a role model's story of persistence seems too far removed from a learner's experience, the learner's sense of "This is not for me" may be reinforced.
Connectivism	Persistence means connecting to different nodes for resources or feedback until success is achieved.	Persistence can be encouraged by pairing low-achievement feedback (e.g. a failed test) with a list of alternative resources relating to the topic (e.g. videos, websites, class mates).	If networks include many low-achieving peers who imply that they are unable to achieve well, a normalisation may occur that encourages helplessness and defeatism.

2.5.3. Effort

Implied in the belief that academic ability is fixed is the idea that if you 'have it' you should find work easy and not need to exert yourself, a belief that may have been reinforced by years of being under-challenged at school. Conversely, a growth mindset view is that effort leads to improvement.

Table 2.4: How effort relates to learning theories and mindsets

Learning theories	How effort relates to each learning theory	Growth mindset: How can students be encouraged to put effort into their work?	Fixed mindset: How can students be (unintentionally) discouraged from putting effort into their work?
Behaviourism	Effort involves observing and modelling the behaviour of an expert (a teacher	Encourage and reward repeated attempts at a task when feedback has been used to make changes. Show graphs	Comparisons with peers who appear to achieve with little effort may make students feel

	or tutor) and using feedback to practice and develop mastery.	of time on task versus improvement from students who use feedback to improve. Provide differentiated activities to keep all students in a class engaged.	discouraged. The reuse of past test questions which have model answers may reward low effort rote learning.
Constructivism	Effort involves working through scaffolded problems to develop meaning; questioning rather than accepting results; exploring alternative approaches to the same problems.	Use checkboxes/rubrics listing sub-steps of expert behaviour and indicating which steps are optional and can be dropped as expertise improves. Ask learners to rate how much effort they put into a task. Include extension options on assignments.	Distant deadlines without interim deadlines may encourage work avoidance. Using only a single type of assessment that favours some learners (e.g. timed tests) can reinforce a fixed mindset.
Communities of practice	Effort involves developing skill in practices that are valued by members of the community and gaining status based on performances evaluated by the community.	Interviews with experts can expose a range of effort-requiring practices that experts use. Case studies on the development of habits that later become less effortful may help explain how expertise is developed.	Clashes between experts on what ‘counts’ (e.g. proofs in engineering mathematics tests) can lead to learners feeling they have wasted effort in learning a skill that is not valued.
Connectivism	Putting effort into academic work involves the meaningful incorporation of information gathered from one’s expanding network of nodes.	Set tasks requiring the use of a variety of resources (e.g. text, video) and multiple steps. Self-reflection can prevent information being gathered with effort but without much learning. Assign	A well-connected learner may feel like they are using effort to gather and use readily available resources (e.g. online calculators like symbolab.com) and may receive credit for solving difficult

		presentations in which learners must compare solutions from different sources.	problems but without the information being meaningfully incorporated by the student.

2.5.4. Praise

Praising ability reinforces the fixed mindset belief that talent and ability are inherited and cannot be developed beyond a basic level. Growth mindsets can be encouraged by praising strategies and effort that lead to success rather than focusing on a final score.

Table 2.5: How praise relates to learning theories and mindsets

Learning theories	**How praise relates to each learning theory**	**Growth mindset: How can praise be used to encourage a growth mindset?**	**Fixed mindset: How can praise be (unintentionally) used to encourage a fixed mindset?**
Behaviourism	Praise is positive feedback that encourages students to repeat behaviour.	When a task is completed successfully, praise more than just final achievement, e.g. improvement, time on task, persistence, focussed attention on a task. Avoid praising effort that did not lead to success.	Highly valued public praise to top achievers (e.g. leader-boards, merit lists, prize-giving ceremonies) may reinforce the belief that only top achievers are valued and may discourage participation when top achievement is not likely.
Constructivism	Praise provides feedback to help learners evaluate the meaning they are constructing for themselves.	Praise efforts to overcome obstacles in the learning process, such as mind-mapping, question-posing, breaking into sub-tasks.	Praise for reaching a level of achievement (e.g. 9/10, top mark in class) may encourage learners to seek easier, repetitive learning activities for which they are more likely to be praised.
Communities of practice	Praise from a more central community	Praise when students ask for help. Showcase	Highly praised celebrity-status community members

	member carries more value.	different styles of high quality work, giving reasons why some elements are seen as having a particularly high standard.	(e.g. award-winning students or teachers) can reinforce a belief that high achievement is only available to some.
Connectivism	Praise received from multiple nodes or popular nodes carries more value.	Praise sourcing notes and examples of similar problems in books, videos, websites, and the work of colleagues.	Over-reliance on a single "best" source can reduce effort if learners feel that the source will make learning easy and without much effort on their part.

2.5.5. The success of others

A growth mindset does not imply that everyone can achieve at the same level in the same amount of time, rather that everyone can improve significantly. Examples of high achievement inspire those with a growth mindset but make fixed mindset people feel threatened that their success will not be valued.

Table 2.6: How the success of others relates to learning theories and mindsets

Learning theories	How the success of others relates to each learning theory	Growth mindset: How can learning from and feeling inspired by the success of others be encouraged?	Fixed mindset: How can feeling threatened by the success of others be (unintentionally) encouraged?
Behaviourism	The outcome of learning is being able to do what experts do. Successful others are models of what can be achieved.	Set tasks that involve observations of successful others who used feedback from failure before achieving success. Credit referring to the work of others.	Students may feel that they will only be successful if they are the same as the success models they observe and give up if they feel this is unachievable.
Constructivism	The outcome of learning is being able to think or construct meaning	Peer tutoring from a more advanced peer may encourage a learner that they can	If your way of constructing knowledge differs from successful

	like an expert. Successful others are approaching expert status.	also achieve the same level of understanding.	others, it may be devalued.
Communities of practice	Success shows legitimate participation in a community of practice. More successful members have a more central part in the community.	Showcase inspiring examples of more successful community members. Include diverse examples of success.	When only a few in the community can achieve success, such as top grades or Olympic gold medallist, the success of others decreases the likelihood of one's own success.
Connectivism	Success can be measured by the number of connections to successful others in your network and your contributions to the network.	Collaboratively solving mathematics problems on large whiteboards allows for easy sharing of ideas from other groups. Make students source, rate and comment on popular YouTube videos on a topic. Anonymity may encourage participation.	Your impact in the community will be lower if there are many successful people competing for the attention of community members. Censoring remarks on online group discussions may be necessary.

2.5.6. Learning goals

From a growth mindset perspective, the point of a learning activity is to improve ability, whereas from a fixed mindset perspective, the main purpose of a learning activity is to display ability.

Table 2.7: How learning goals relate to learning theories and mindsets

Learning theories	**How learning goals relates to each learning theory**	**Growth mindset:** **How can self-improvement learning goals be encouraged?**	**Fixed mindset:** **How can a focus on grades rather than learning be**

			(unintentionally) encouraged?
Behaviourism	Feedback reinforces expert-like behaviour and reduces non-expert-like behaviour. Learning is moving towards expert behaviour.	Give feedback on test papers in the form of written comments, without grades. Record the grades and release them only after students have engaged with the feedback and made corrections or completed a post-test questionnaire or 'test wrapper'.	If performance is competitive and results are publicly displayed or discussed, those perceived as low achievers may feel shame and self-sabotage their future learning by not doing the work that can lead to improvement.
Constructivism	You learn when you think or construct meaning like an expert.	After receiving feedback from a teacher on work with errors, students make corrections and resubmit with notes on how they can avoid similar errors in future tasks.	If there are no opportunities to demonstrate learning from mistakes, such as make-up assignments or future assessments on the same topics, feedback is more likely to be ignored.
Communities of practice	You will have learnt when you can legitimately participate in a community of practice and gain a more central part in the community.	Students self-assess their achievement of learning goals in a rubric, justifying with evidence from class activities such as tests, presentations, mastery quizzes, setting questions for peers. Teachers negotiate when justification is weak. Online badges can	Students may strategize or even cheat to achieve badges or give inflated self-assessments if the community privileges experts far above others.

		identify members with more expertise.	
Connectivism	You will have learnt when you have connections to successful others in your network and contribute to the network.	Create voluntary tutoring groups on a social media platform where past students answer questions from current students.	Students may think, "People see me as smart. I have many followers. I may post things I don't really believe or understand but that's okay since I stay popular."

2.6. Conclusion

The landscape of theories on teaching and learning is vast and dynamic. In a single day, a student may engage with behaviourism-inspired videos with mastery quizzes, connect on social media to a community of practice for advice on solving a homework question, use responses to help their construction of understanding of a topic, and post a social media comment where they share their understanding and the resources that helped them. The student's self-beliefs will shape their behaviour as they navigate these tasks. In particular, growth mindset beliefs will make the student more likely to behave in ways that lead to deeper learning, openness to feedback and persistence after academic setbacks, all of which should lead to more successful long-term learning.

Whatever learning theories guide the design of our learning activities, we have the power to influence growth or fixed mindsets through our instructional design, whether or not we intend to do so. Using six tables, each on a characteristic of growth and fixed mindsets, namely *challenges, persistence, effort, praise, success of others* and *learning goals*, in relation to four learning theories, namely *behaviourism, constructivism, communities of practice* and *connectivism*, we have presented a framework with suggestions of activities that send growth mindset messages to students and potential ways in which fixed mindsets may inadvertently be promoted. While the layout of the tables may suggest that there is a binary divide between fixed and growth mindset beliefs and behaviour, in reality they exist on a continuum. Readers need to determine which approach is best suited to their own contexts.

Here is an example of how an academic could draw on the tables above when considering how to respond to a standardised test that most students failed. She initially considers showing her class that their low performance is slightly better than the average of the larger group but refrains as this could encourage normalising their performance instead of focusing on improving. Instead, after engaging with the tables, she encourages persistence by speaking about previous students who had low results but improved when they tried different learning strategies. After watching a video clip where a slightly older student explains how they study, she asks her students to collaboratively construct a list of different strategies and resources they could use when studying mathematics. In future classes, the list is referred to and students are required to write about what new strategies or resources they have they have been using.

Growth mindsets appear to be especially valuable to academically high-risk students and students from low-income households (Sisk et al., 2018), and promoting growth mindsets may contribute to societal goals of economic upliftment. On the other hand, fixed mindset ideas of ‘being a maths person’ may help successful students to construct an identity of themselves that influences their decision to continue studying mathematics (Bartholomew, Darragh, Ell & Saunders, 2011). The danger of holding a fixed mindset, however, is that it leaves students more vulnerable to dropping out when challenges arise. As educators, we should be aware of the mindset messages we are sending, regardless of the learning theories driving our learning activities.

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2.7. Reflection

In this chapter I defined how each of six mindset characteristics (dealing with challenges, persistence, effort, praise, the success of others and learning goals) related to the four learning theories of behaviourism, constructivism, communities of practice and connectivism and gave examples of how both fixed mindsets and growth mindsets can be encouraged through learning activities corresponding to each learning theory. I concluded that promoting growth mindsets does not depend on the learning theory that drives an educator’s teaching activities. Educators should be aware that even without intending to, they may be sending subtle and unintended signals to students that can encourage both fixed or growth mindsets.

Feeling convinced that developing growth mindsets was not a matter of adopting a particular learning theory, I moved my attention to exploring the types of mindset interventions that have been applied to engineering students. I found many variations in mindset interventions, including differences in the ways that mindsets were assessed, which made it difficult to discern what types of interventions were effective. A systematic literature review was identified as a gap-filling and important contribution to engineering education literature, and this is the focus of chapter three.

Chapter 3: Literature review

3.1. Chapter introduction

The research question driving the systematic literature review in this chapter is, *How effective are different interventions to develop growth mindset in engineering students?* The motivation to undertake a systematic literature review was to make it easier for educators to use previous research literature on mindset interventions when planning their own interventions. It also directly supported the main thesis research question, *How can growth mindsets be developed in engineering students?*

In collaboration with an experienced engineering education researcher who has a psychology background, and checking assistance from a colleague, I searched 12 databases that covered literature from education, engineering and psychology and assessed 642 studies returned from the comprehensive search string that aimed to limit results to intervention studies using Dweck's mindset theory and involving engineering students. After removing 101 duplicate studies, and assessing 526 studies, 15 studies were found to meet the inclusion criteria.

The results have been written as a journal article which is currently under review. A conference paper of the work-in-progress for this literature review was published in the proceedings of the European Engineering Education SEFI 2019 conference. The reference to this paper can be found on page vi.

Campbell, A., Direito, I. & Mokhithi, M. (Submitted for review). Developing growth mindsets in engineering students: A systematic literature review of interventions. *European Journal of Engineering Education*.

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3.2. Abstract

Dropout from engineering studies has been linked to 'fixed mindset' beliefs of intelligence as fixed-at-birth that make students more likely to disengage when facing new challenges. In contrast, 'growth mindset' beliefs that intelligence can be improved with effort make students more likely to persist when confronting difficulties. This systematic literature review of engineering, education and psychology databases explores the effectiveness of different interventions in developing growth mindset in engineering students, what measures have been used in assessing the effectiveness of these interventions and who has benefited from these interventions, in terms of gender and year of study. We compare interventions by geographical location, intervention type, methodology for assessing mindsets, other topics studied, and effectiveness. The results show a variation in effectiveness among the fifteen included studies. The findings will be useful for educators who want to encourage growth mindset and thereby support the academic success of their students.

Keywords: Growth mindset; beliefs; intervention; theories of intelligence; student success

3.3. Introduction

To meet stakeholder expectations, engineering educators are expected to produce graduates with a broader range of skills and attributes than in the past. The extra demands on students in a rapidly changing learning environment, increased diversity within engineering programmes, and education system weaknesses regarding diversity makes it more likely that some engineering students will encounter setbacks in their studies (Good, Rattan & Dweck, 2012; Pierrakos, 2017; Jungert, 2008). Beliefs about intelligence influence students' academic behaviour, particularly after a setback, such as failing an assignment. Students with fixed mindsets believe that intelligence is a fixed trait (Dweck & Leggett, 1988) and may feel that they are not the 'type' for engineering if success does not come easily. Growth mindsets defend against disengagement from studies when encountering challenges because success is believed to be a result of improving intelligence and ability through applying appropriate effort (Henry, Shorter, Charkoudian, Heemstra & Corwin, 2019; Stump, Husman, & Corby, 2014).

There have been diverse approaches to the definition and study of intelligence. Despite these differences, intelligence, and intellectual functioning, can be defined as the ability to implement goal-directed adaptive behaviour (Sternberg, 2004). The theories of intelligence are normally organized in two groups: explicit and implicit. Explicit theories of intelligence "are constructions of psychologists or other scientists that are based on or at least tested on data collected from people performing tasks presumed to measure psychological functioning" (Sternberg, 1985, p.607), and have dominated this field of study. Examples of explicit theories are: psychometric theories, which have sought to explore the (hierarchical) structure of intelligence and test mental abilities (e.g. Spearman's general intelligence, or g factor); cognitive theories, to which intelligence is composed by mental representations and mental processes that can operate on those representations; cognitive-contextual theories, which expanded cognitive theories by taking into account the multiple contexts where cognitive processes operate (e.g. Gardner's theory of multiple intelligences); and biological theories, which are based in the neuropsychological processes of intelligent behaviour.

On the other hand, implicit theories are elicited by asking people what they mean by intelligence through interaction and interpretation of their environment. These theories "are constructions by people (whether psychologists or laypersons) that reside in the minds of these individuals (…) Discovering such theories can be useful in helping to formulate the common-cultural views that dominate thinking about a given psychological construct, whether the culture be one of people, in general, or of psychologists, in particular." (Sternberg, 1985, p.608). Dweck et al. (1995) developed a theoretical model of how a person's beliefs and assumptions about themselves has an impact on their judgements and behaviours. The model of Implicit Theories refers to two antagonist types of assumptions that people make about their own attributes. For example, people "may believe that a highly valued personal attribute, such as intelligence and morality, is a fixed, nonmalleable trait like entity (*entity theory*), or they may believe that the attribute is a malleable quality that can be changed and developed (*incremental theory*)" (id, p.267). According to this model, a person holding an entity theory believes that intelligence is a fixed trait that cannot be changed no matter what (fixed mindset); whereas a person with an incremental theory believes that intelligence is dynamic and can be changed with strategic effort (growth mindset). With this model, Dweck does not attempt to define intelligence. Instead, her research focuses on how people's theories about their intelligence, or their intellectual potential, (i.e. self-theories) can impact their behaviour - how peoples' believes can enhance, or hinder, their motivation and learning. More precisely, her research aims to understand "what are the psychological mechanisms that enable some students to thrive under challenge, while others of equal ability do not?" (Blackwell, Trzesniewski, & Dweck, 2007, p.247)

The model of Implicit Theories is particularly useful to understand human behaviour in adverse contexts. A person with a fixed mindset is "more likely to blame their intelligence for negative outcomes". In contrast, a person with a growth mindset is "more likely to understand the same negative outcomes in terms of their effort or strategy" (Dweck, Chiu, & Hong, 1995, p.267).

To assess these implicit theories, Dweck and colleagues developed self-reported questionnaires. Mindsets are typically assessed using Dweck's Implicit Theories of Intelligence scales, with three items (Dweck, Chiu & Hong, 1995), eight items (Dweck, 2000; Dweck, 2006), four or six items (Dweck, 2000), or adaptations of these (for example De Castella & Byrne, 2015; Karwowski, 2014). Respondents are asked to choose their level of agreement with each statement using a 6-point Likert scale, where 1 means 'strongly agree' and 6 means 'strongly disagree'. The mindset score corresponds to an average of the items (ranging from 1 to 6), with a score of 3, or below, suggesting a stronger growth mindset, and a score of 4, or above, suggesting a fixed mindset (Dweck, Chiu & Hong, 1995).

Table 3.1. Implicit theories of intelligence scale – versions and items

Scale	**Items**
3 items	1. You have a certain amount of intelligence, and you really can't do much to change it. 2. Your intelligence is something about you that you can't change very much. 3. You can learn things, but you can't really change your basic intelligence.
4 items	1. You have a certain amount of intelligence, and you really can't do much to change it 2. Your intelligence is something about you that you can't change very much 3. To be honest, you can't really change how intelligent you are. 4. You can learn new things, but you can't really change your basic intelligence.
6 items	1. You have a certain amount of intelligence, and you really can't do much to change it 2. Your intelligence is something about you that you can't change very much 3. You can learn new things, but you can't really change your basic intelligence. 4. No matter who you are, you can change your intelligence a lot (*). 5. You can always greatly change how intelligent you are. (*) 6. No matter how much intelligence you have, you can always change it quite a bit. (*)
8 items	1. You have a certain amount of intelligence, and you really can't do much to change it

	2. Your intelligence is something about you that you can't change very much 3. No matter who you are, you can significantly change your intelligence level (*). 4. To be honest, you can't really change how intelligent you are. 5. You can always substantially change how intelligent you are. (*) 6. You can learn new things, but you can't really change your basic intelligence. 7. No matter how much intelligence you have, you can always change it quite a bit. (*) 8. You can change even your basic intelligence level considerably. (*)
	Note: items marked with (*) need reverse scoring

Psychosocial support in higher education can improve gender and race equality in STEM disciplines (Casad et al., 2018; Fong et al., 2017). Developing growth mindsets is valuable for engineering education because, compared to fixed mindset students, growth mindset students are more likely to adapt and succeed in demanding or stressful situations (Costa & Faria, 2018), to have favourable views on the benefits of group work (Alpay & Ireson, 2006), to set learning goals rather than focusing on grades (Robins & Pals, 2002), to have greater well-being (Ortiz Alvarado, Rodríguez Ontiveros & Ayala Gaytán, 2019), and to support policies aimed at redressing social inequality (Rattan, Savani, Naidu & Dweck, 2012). When mistakes are viewed as learning opportunities instead of judgements about fixed traits, students are more willing to participate and demonstrate the perseverance and resilience needed for creativity and innovation (Dweck, 2006). Growth mindsets may also help with retention of engineering students. For example, Heyman, Martyna, and Bhatia (2002) found that all of the female students who dropped a course after encountering academic difficulties had fixed mindsets.

Following Carol Dweck's popular book on mindsets (Dweck, 2006) and TED Talk (Dweck, 2014), there was an increase in growth mindset correlation studies (e.g. Bostwick, Martin, Collie, & Durksen, 2019) and growth mindset intervention studies (e.g. Paunesku et al., 2015), mostly in school contexts. Research on post-school growth mindset interventions seemed to include few interventions involving university students studying engineering. In addition, a meta-analysis by Sisk, Burgoyne, Sun, Butler and Macnamara (2018) found that growth mindsets did not consistently correlate with higher grades and that some intervention studies gave unexpected mixed results (Yeager et al., 2016). As more engineering educators take tentative steps to include psychosocial support in their teaching, a systematic review of growth mindset interventions that have already been applied to engineering students will allow educators to make informed decisions when designing their own growth mindset interventions and choosing how to assess the effects of interventions. As suggested by Borrego, Foster and Froyd (2014), this systematic review compiles and synthesises relevant interdisciplinary studies, and informs engineering education practice. Ultimately, it can guide and accelerate the application of effective growth mindset interventions with engineering students. This systematic literature review addresses the research questions:

1. How effective are different interventions to develop growth mindset in engineering students?
2. What measures have been used in assessing the effectiveness of these interventions?
3. Who benefited from these interventions, in terms of gender and year of study?

The answer to these questions will help engineering educators plan growth mindsets interventions based on previous scholarship that involved engineering students.

3.4. Method

We followed the procedures for a systematic literature review involving engineering education research outlined in Borrego, Foster and Froyd (2014). This involved:

- Defining the inclusion criteria.
- Finding and cataloguing sources.
- Assessing the quality of each identified study.
- Synthesising the included results.

3.4.1. Defining the inclusion criteria

Search terms were created to find studies that met the following conditions:

1. The interpretation of 'growth mindset' aligned with Dweck's theory of mindsets.
2. The intervention involved engineering students in tertiary studies (college or university).
3. The research design involved an intervention aimed at developing growth mindsets.

The exact search terms used are presented in Table 3.2.

Table 3.2. Search terms used in databases.

("growth mindset" OR "growth mindsets" OR “fixed mindset” OR “fixed mindsets” OR "incremental mindset" OR "incremental mindsets" OR "malleable intelligence" OR "implicit theories of intelligence")	AND (“engineering student” OR “engineering students” OR “engineering class” OR “engineering classes” OR “engineering classrooms” OR “incoming first-year students”)	AND (intervention OR interventions OR experiment OR experiments OR measure OR measurement OR compare OR comparison)

Where a database allowed, a suffix of * was used for multiple endings, e.g. compar* for compare and comparison. Some databases, e.g. Engineering Village, did not allow the use of * inside quotation marks. Where the search string was too long for the database (e.g. JSTOR), multiple searches were made to eliminate phrases that did not produce more results. Two subject librarians validated the iterative development of the search string and confirmed that it met the inclusion and exclusion criteria. The inclusion and exclusion criteria, with rationales, are presented in Table 3.3.

Table 3.3. Inclusion and exclusion criteria for mindset intervention studies

Category	**Inclusion criteria**	**Exclusion criteria**	**Rationale**
Publication type	Peer-reviewed journal articles, conference papers, books, book chapters and doctoral dissertations.	Not peer-reviewed.	Quality assurance of the research; more credible results.
Publication language	Publications in any language found from database searches using English search terms.	Article not able to be translated into English, or translation quality weak.	The number of translations required were small; including more studies increases the value of the review.
Participants	Engineering students and students sharing classes with engineering students.	Not involving engineering students as the group targeted for the intervention.	The research questions target engineering students in post-school settings.
Purpose of intervention	The intervention aims to develop growth mindsets, or changes in mindset are reported.	The intervention does not aim to develop growth mindsets, or there is no	The research questions focus on developing growth mindsets.

		assessment of students' mindsets.	
Theory used	Dweck's (1986, 2008) theory of growth/incremental and fixed/entity mindsets.	A use of the term 'mindset' different from Dweck's theory.	The research questions focus on Dweck's theory of mindsets.
Outcome measures	An assessment of the effectiveness of the intervention is made.	No assessment of the intervention is made.	The research questions ask for measures for assessing the effectiveness of the intervention.
Date	Published before 1 January 2020 and after 31 December 1982.	Published after 1 January 2020 and before 1 January 1983.	A final check for new results was made on 1 January 2020. Dweck's work on growth mindsets was not available before 1983.

3.4.2. Finding and cataloguing sources

A comprehensive literature search for journal articles, conference papers, books, book chapters and doctoral dissertations was carried out before and on 1 January 2020. Engineering, education and psychology databases listed in Borrego, Foster and Froyd (2014) and others available through our institutional libraries were searched.

A total of 642 records were returned from the 12 databases listed in Table 3.4. From these, 101 duplicate records were removed. A spreadsheet with details (author, title, date published, abstract, type of resource, journal/conference/university name, database, reason for exclusion) for the remaining 541 records was compiled by the first author with advice and some additions by the second author and checking by the third author. A total of 520 records were excluded on the basis of abstracts or scanning the full text for evidence of a growth mindset intervention involving engineering students. The remaining 21 records that seemed to meet inclusion criteria were analysed in the spreadsheet using a further 10 headings: location of study, purpose/objectives of study, research questions, students targeted (year of study, demographics, course), details of intervention (duration, incentives, facilitator training), alternatives to intervention (e.g. no intervention, control group with similar activity), outcome measures (scales, interviews, course results), findings, quantitative/qualitative/mixed design, measures of treatment effect.

Table 3.4. Number of duplicated, included and excluded records

Database	Total records	Duplicates	Excluded	Included
Academic Search Premier	2	1	1	0
Education Database	87	19	67	1
Engineering Village	13	9	2	2
ERIC	3	2	0	1
JSTOR	3	2	1	0
Proquest Dissertations and Theses	373	40	327	6
PsycARTICLES	1	0	1	0
PsycINFO	2	2	0	0
ScienceDirect	7	0	7	0
Scopus	126	18	104	4
Web of Science	4	3	0	1
Wiley Online Library	21	5	16	0
Total	**642**	**101**	**526**	**15**

Exclusion reasons for the 526 excluded records were: not having a growth mindset intervention and/or not involving engineering students (n = 517), not having one of the included research formats (i.e. journal article, conference paper, book, book chapter or doctoral dissertation, n = 6), not including an assessment of the effectiveness of the intervention (n = 2) and not being able to include on the basis of the abstract or acquire the full text (n = 1).

Six records were excluded after a full analysis, leaving 15 included results. The 15 included records came from 2 out of 132 journal articles, 6 out of 59 conference papers, and 7 out of 426 doctoral dissertations. No records were included from books and book chapters.

The flow diagram in Figure 3.1 represents the literature review process and number of records at each stage.

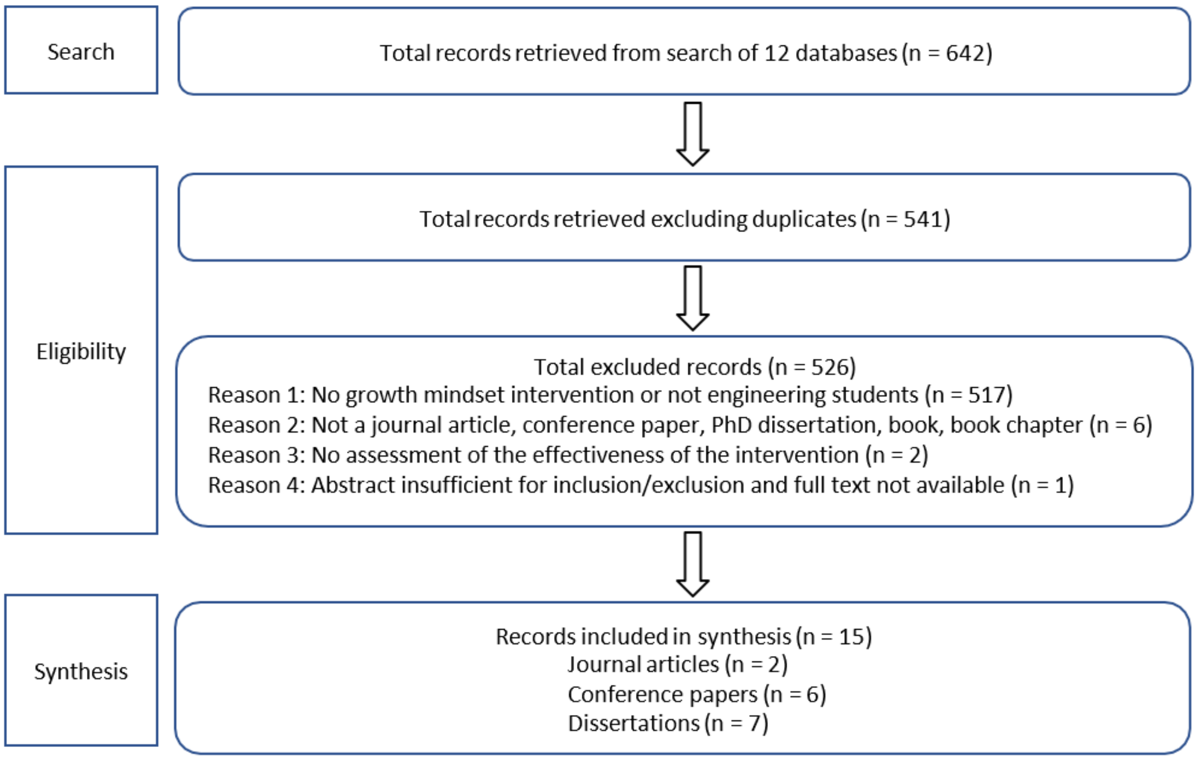

Figure 3.1: Flow diagram for the selection and analysis of included literature

3.4.3. Synthesising the included results

The included studies were compared in terms of types of intervention; methodologies used; other topics addressed in the studies in addition to mindsets, effectiveness of studies, and who benefited (in terms of gender and year of study). The results are summarised in the table in the appendix under headings *Research design* (including qualitative/quantitative/mixed methods, variables, duration of intervention, population), *Details of intervention*, and *Findings*.

3.5. Results

3.5.1 Geographic distribution of studies

The vast majority of included studies were based in the United States of America, including all seven PhD dissertations. The two oldest included studies [#4, 14] involved universities and authors from the United Kingdom.

A possible limitation of this review was that restricting the search terms to English may have limited the number of eligible studies. Only one result was in a language other than English (Arabic), and after assessing the translated abstract, using Google Translate, the article was excluded. Results may have been missed due to our unfamiliarity of mindset terms specific to other cultures.

3.5.2 Types of interventions

The dominant intervention, seen in ten of the studies, was sharing mindset ideas with students through readings [#1, 5, 6, 8, 11], videos [#8, 12], lectures [#4, 6, 14], or online tutorials [#7, 9], followed by discussion or reflective writing, including students writing advice for other students. One of those studies [#4] also used two other interventions: a 'crib sheet' of alternative strategies when a computer programme fails (to counter the fixed mindset approach of re-trying the same strategy or giving up when stuck), and feedback on assignments stating that students who put in time and effort usually succeed. Growth mindset messages were included in mathematics word problems in study #2. Two studies involved introductory courses designed to increase growth mindsets [#3, 15]. One study [#10] used open-ended projects as a means of encouraging growth mindsets by valuing alternative strategies rather than a single correct answer. The remaining study [#13] involved the use of a course-embedded writing tutor to influence students' mindsets.

3.5.3 Methodologies to assess mindsets

The dominant methodology was quantitative (nine studies) or mixed methods (five studies). Different versions of mindset scales were used to classify students on the spectrum of fixed to growth mindsets, as detailed in Table 3.5. The eight-item scale was developed to address two possible concerns: firstly, whether disagreement with fixed mindset items really does correspond with holding a growth mindset, and secondly, that including only fixed mindset items may encourage 'universal endorsement' by participants rather than assessing their beliefs. Two validation studies described in Levy, Stroessner & Dweck (1998) found that disagreement with fixed mindset items did represent agreement with growth mindset items, and that the three-item and eight-item scales had high correlation (0.83 and 0.92). Dweck (2000) supported the use of the six-item scale for children and the eight-item scale with adults. Hong, Dweck, Chiu, Lin & Wan (1999) argue that the three-item mindset scale has high internal validity and avoids the problem with "continued repetition of the same idea becomes somewhat bizarre and tedious to the respondents."

Of the fourteen studies that included quantitative data, nine studies [#1, 2, 3, 6, 7, 11, 12, 14, 15] used original mindset scales and three [#8, 9, 13] used modified items, for example, “Music talent can be learned by anyone,” [#8]; “You can learn new things, but you can't really change your math intelligence,” [#9]; and “Good writers are born, not made,” [#13]. Six studies used three-item scales [#1, 2, 7, 9, 11, 14] and four used eight-item scales [#3, 12, 13, 15]. Other versions used four items [#6], sixteen items [#8] and 27 items [#11]. One study [#13] asked an additional three mindset-focussed questions on talent versus effort, two of which were open-ended.

Qualitative data included analysis of students’ reflective answers, interviews and focus group discussions. The only qualitative study used thematic analysis of students’ written responses to reading group discussions of Dweck’s (2008) book *Mindset: The new psychology of success* [#5].

Table 3.5. Mindset assessment tool details

Study number	Items in scale	Likert options	Item modification	Reference for mindset scale
11	3	5	Original	PERTS (2015)
1	3	6	Original	Hong, Chiu, Dweck, Lin, & Wan (1999)
2	3	6	Original	Dweck (2000); Hong, Chiu, Dweck, Lin, & Wan (1999)
7	3	6	Original	Hong, Chiu & Dweck (1995)
14	3	6	Original	Dweck (2000)
9	3	7	Modified: Maths	Dweck (2000)
6	4	7	Original	Dweck (2000)
15	8	5	Original	Dweck (2006)
3	8	6	Original	Dweck (2006)
12	8	6	Original	Dweck (1999/2000)
13	8	6	Modified: Writing	Palmquist & Young (1992); Dweck (2000); Limpo & Alves (2014)
8	16	7	Modified: Music, Maths	Dweck (2000)
10	27	Unspecified	Unspecified	"Authored by Dweck"
5	No scale	No scale	n/a	For discussion prompts: Dweck (2006)

Study number	Items in scale	Likert options	Item modification	Reference for mindset scale
4	Unspecified	Unspecified	Unspecified	"Dweck's general mindset measure"

Table 3.9: 'Summary of included studies' in the Appendix at the end of this article summarises the research design, interventions and findings of the 15 included studies.

3.5.4 Effectiveness of studies

The following definitions were used to categorise studies as effective, inconclusive or not effective:

Effective:

- Statistically significant ($p<0.05$) change in mindset score from pre- to post-intervention survey OR
- Statistically significant ($p<0.05$) difference in post-intervention mindset score between intervention and control groups when there was no pre-intervention mindset score OR
- Large ($|r|>=0.7$) matched-pairs correlations for pre- and post-intervention mindset scores OR
- Qualitative data supporting author's conclusion that intervention was effective.

Inconclusive:

- Insufficient details to categorise study as effective or not effective OR
- Weak ($0.3<|r|<0.7$) matched-pairs correlations for pre- and post-intervention mindset scores OR
- Mixed results for different groups within a study OR
- No data (work-in-progress study).

Not effective:

- No statistically significant change in mindset score from pre- to post-intervention survey OR
- No statistically significant difference in post-intervention mindset score between intervention and control groups when there was no pre-intervention mindset score OR

- No ($|r|<0.3$) matched-pairs correlations for pre- and post-intervention mindset scores OR
- Qualitative data supporting author's conclusion that intervention was not effective.

Table 3.6 shows the study conclusions, reasons for conclusions, initial mindset scores and final mindset scores. To enable comparisons over scales with different number of Likert options, mindset scores were converted to percentages. Firstly, scales where higher values indicated fixed mindsets were reversed, for example a score of 5 on a scale from 1 to 6 where higher values indicate fixed mindsets would be converted to 2 on a scale from 1 to 6 where higher values indicate growth mindsets. Secondly, mindset scores were converted to percentages using the formula

$$\text{Mindset score \%} = \frac{(\text{mindset score} - \text{lowest value on scale})}{(\text{highest value on scale} - \text{lowest value on scale})}.$$

For example, on a scale of 1 to 6, a score of 3.5 would be 50%, a score of 3 would be 40% and a score of 6 would be 100%.

Table 3.6. Study conclusions, reasons for conclusions, initial and final mindset scores as percentages of scales

Study number	Study conclusion	Reason for study conclusion	Initial mindset scores (0% = fixed mindset, 100% = growth mindset)	Final mindset scores (0% = fixed mindset, 100% = growth mindset)
3	Effective	Large matched-pair correlations (growth mindset r = .90 and fixed mindset r=-.80); large effect sizes (0.54 growth, 0.48 fixed).	55.0%	77.0%
4	Effective	Sig. difference in mindset score changes between intervention and control groups (p<0.044).	52.4% (control) 54.2% (intervention)	47.8% (control) 58.6% (intervention)
7	Effective	Sig. higher mindset score for intervention vs. control or comparison groups (p<0.001).	No pre-test	64.0% (control) 63.8% (comparison) 75.0% (intervention)
9	Effective	Sig. higher post-intervention mindset score for mindset intervention group vs. control (p=0.035).	68.5% (control) 65.5% (mindset intervention)	63.5% (control) 68.8% (mindset intervention)

Study number	Study conclusion	Reason for study conclusion	Initial mindset scores (0% = fixed mindset, 100% = growth mindset)	Final mindset scores (0% = fixed mindset, 100% = growth mindset)
13	Effective	Intervention group "improved their mindsets more significantly than students in the control and comparison groups."	Not given (full text not available)	Not given
1	Inconclusive	Mixed results for different groups. Sig. change in GPA for Latina/o students (p<0.002).	75.4% (control) 74.8% (intervention)	No values given
5	Inconclusive	No assessment of a change in mindset. Insufficient data.	n/a	n/a
8	Inconclusive	Insufficient details. Sig. not calculated, graph suggests a sig. change in mindset; mixed qualitative responses.	No values given	No values given
10	Inconclusive	Insufficient details. Intervention seems to reduce trend towards fixed mindsets over 1st year.	48.4% (control) 37.4% (intervention)	46.6% (control) 37.6% (intervention)
14	Inconclusive	Sig. changes in mindset scores for some survey items but in different directions (p=0.033, 0.004 and 0.011 respectively for listed mindset changes).	For two fixed mindset items: 55.2% (control) 51.4% (intervention B) 66.5% (intervention C)	For two fixed mindset items: 50.6%% (control) 65.8% (intervention B) 45.6% (intervention C)
2	Not effective	No sig. effects on mindset scores. Math test scores decreased.	75.8% (intervention group 1) 76.6% (intervention group 2)	72.0% (intervention group 1) 83.8% (intervention group 2)
6	Not effective	No sig. effects of interventions on mindset assessment.	70.3% (in-class intervention, n=66) 69.5% (reading group, n=6)	73.3% (in-class intervention) 75.0% (reading group)
11	Not effective	No sig. effect of intervention on academic performance, units completed or retention.	62.5% (average)	No values given
12	Not effective	No sig. difference in mindset scores between intervention and control groups.	58.5% (average)	No values given
15	Not effective	No sig. difference in mindset scores between intervention and control groups.	76.4% (control) 70.2% (intervention)	76.9% (control) 70.5% (intervention)

Five studies [#3, 4, 7, 11, 13] reported that the mindset interventions were effective. Small, statistically significant difference in mindset score changes between intervention and control groups were found in two studies [#4, #9]. Study #7 did not use pre-intervention mindset assessment but found significantly higher post-intervention mindset scores for the intervention group compared to control or comparison groups. While values were not available to assess the extent of growth mindset development in study #13, statistically significantly higher changes in mindset score were reported for the intervention group compared to control or comparison groups. Only one study, [#3], reported large effect sizes for the mindset intervention.

Five studies [#1, 5, 8, 10, 14] were inconclusive regarding the effect of the intervention on developing growth mindsets. Study #1 showed mixed results for different groups. Study #5 did not provide sufficient details from which a change in mindsets could be determined. Studies #8 and #10 did not provide sufficient details for classification as effective or not effective. In addition, study #8 had mixed qualitative responses and study #10 showed that although mindset scores did not move towards growth mindsets, the intervention offset a trend towards fixed mindsets that was observed in a previous year. Mixed results across intervention groups were reported in study #14.

Five studies [#2, 6, 11, 12, 15] reported that the mindset interventions were not effective. Studies #2, 6, 12 and 15 found no significant change in mindset as a result of the intervention. In addition, study #12 found no significant effect on motivation, engineering identity, course grades, GPA and retention. Study #11 found no significant effect on academic performance, units completed or retention.

The effectiveness of interventions was quite evenly distributed among study size. Effective studies comprised 1 of the 3 small studies, 2 of the 5 medium studies and 2 of the 7 large studies. 'Not effective' studies comprised 2 of the 5 medium studies and 3 of the 7 large studies. Inconclusive studies comprised 2 of the 3 small studies, 1 of the 5 medium studies and 2 of the 7 large studies.

The effectiveness of interventions was also quite evenly distributed among the types of interventions, as shown in Table 3.7. Three types of interventions were used exclusively in effective interventions: an introductory course *Engineering the Mind* aimed at developing growth mindsets [#3]; sharing mindset ideas through online tutorials followed by discussion/reflective writing [#4, 7, 9]; and interaction with an embedded writing tutor in an engineering course [#13].

Table 3.7. Types of interventions and effect sizes in mindset intervention studies

Study number	Study conclusion	Type of intervention	Effect size
3	Effective	Introductory course *Engineering the Mind* aimed to develop growth mindset	Large, matched-pairs rank-biserial correlations were r = 0.90 and −0.80 for growth and fixed mindset. Large effect sizes were calculated for growth and fixed mindset: 0.54 and 0.48, respectively.
4	Effective	Sharing mindset ideas through lectures; discussion/reflective writing	Significant difference between intervention and control groups ($F(1,75)=4.18$; $p<.044$).
7	Effective	Sharing mindset ideas through online tutorials; discussion/reflective writing	Post-test, treatment group mean mindset scores (4.75) were significantly higher ($p < 0.001$) than the mean mindset scores of both comparison (4.19) and control groups (4.20), where scores range from 1 to 6. Average GPAs in treatment group (3.10) were significantly higher than the control group (2.86) but not the comparison group (3.03).
9	Effective	Sharing mindset ideas through online tutorials; discussion/reflective writing	Even after controlling for demographics, course sections, pre-survey scores, and test 1 scores, the growth mindset group ($b=.235$, $SE=.097$, $p=.035$, $d=.235$) had significantly higher post-survey intelligence beliefs than the control group.
13	Effective	Interaction with an embedded writing tutor in an engineering course	Data from 36 students who completed pre- and post-intervention surveys showed that students who received the embedded tutoring intervention improved their mindsets more significantly than students in the control and comparison groups. (Values not available.) Students' final drafts were also substantially better in terms of organization, style, and mechanics.
1	Inconclusive	Sharing mindset ideas through readings; discussion/reflective writing	Mixed results for different groups. Latino/a students who received the growth mindset intervention had significantly higher first-semester GPAs (3.13 vs 2.73 on a scale of 0 to 4, $p<0.01$), 2nd semester GPAs (2.97 vs. 2.64, $p<0.02$) and 1st year cumulative GPAs (3.05 vs. 2.69, $p<0.002$) than their peers in the control group.
5	Inconclusive	Sharing mindset ideas through readings; discussion/reflective writing	No quantitative data. Students reconsidered past interpretations of experiences and projected forward on possible changes towards a growth mindset. Students understood that

Study number	Study conclusion	Type of intervention	Effect size
			growth mindset "was not an all or nothing switch to be flipped."
8	Inconclusive	Sharing mindset ideas through readings and videos; discussion/reflective writing	50% of students shifted to a stronger growth mindset post-intervention. No effect size given.
10	Inconclusive	Open-ended projects	No significant increase in growth mindsets. Intervention group shifted less towards fixed mindsets compared to control and previous year groups.
14	Inconclusive	Sharing mindset ideas through lectures; discussion/reflective writing	Some statistically significant changes but not all in the same direction. For the two fixed mindset items pre- to post-intervention mean scores (on a 1 to 6 scale) were 3.57 to 4.29 ($p = .033$, intervention B), 3.66 to 3.28 ($p = .004$, intervention C) and 3.76 to 3.53 ($p = .011$, control).
2	Not effective	Mindset-endorsing mathematics word problems	No significant changes in mindset beliefs. Students' performance on a 30-item challenge activity and 10-item mathematics quiz decreased between pre-test and a post-test three weeks later.
6	Not effective	Sharing mindset ideas through readings and lectures; discussion/reflective writing	The change towards growth mindsets on pre- and post-surveys showed no statistically significant difference.
11	Not effective	Sharing mindset ideas through readings; discussion/reflective writing	After 2 years there was no effect of either the growth mindset or the belonging intervention on academic performance, units completed, or retention.
12	Not effective	Sharing mindset ideas through videos; discussion/reflective writing	No significant difference in mindset between the mindset intervention and control conditions (Wilks' λ (386, 2) = .99, $p = .12$, partial $\eta 2 = .011$).
15	Not effective	Introductory course *On Course* aimed to develop growth mindset	No significant difference between mindset means for the pre-test (intervention mean = 60.95, sd = 10.02, n = 85; control mean = 64.88, sd = 8.31, n = 18) and post-test (intervention mean = 61.09, sd = 10.46, n = 61; control mean = 65.23, sd = 11.26, n = 13) on a scale from 16 to 80. Black first-generation learners had a significantly higher mean difference in pre- and post-test scores (7.1) than white first-generation learners ($\rho = .034$).

3.5.5 Who benefited?

Overall, the included studies focussed on first-year students. Only two studies [#3, 8] were not directed at first year students. Both were small studies (15 and 26 students) with 20-23% female participants. Study #3 reported the greatest changes in mindset scores while study #8 was inconclusive.

Only seven of the studies reported the percentage of female participants. Two of the effective studies [#7, 9] stood out for having very high female participation (61% and 79%) as well as being large studies (n = 489 and n = 426). Two of the five studies that were not effective [#11, 12] reported much lower female participation (16% and 25% female) and were also large studies (n = 441 and n = 1021). The largest study, [#1] had 50% female participants but was inconclusive. Table 3.8 summarises the study conclusions, study sizes, study year of participants and percentage of female participants.

Table 3.8. Mindset intervention conclusions, study size, participants' year of study and percentage female participants

Study number	Study conclusion	Number of students	Study size	Participants year of study	Female participants
3	Effective	15	Small	1 (27%), 2 (20%), 3 (60%), 5 (7%), 6 (7%)	20%
4	Effective	89	Medium	1	Unknown
7	Effective	489	Large	1	61%
9	Effective	426	Large	1 (83%), 2 (11%), 3 (5%)	79%
13	Effective	57	Medium	unknown	Unknown
1	Inconclusive	7686	Large	1	50%
5	Inconclusive	8	Small	1	Unknown
8	Inconclusive	26	Small	3	23%
10	Inconclusive	84	Medium	1	Unknown
14	Inconclusive	228	Large	1 (mostly)	Unknown
2	Not effective	73	Medium	unknown	Unknown
6	Not effective	66	Medium	1	Unknown
11	Not effective	441	Large	1	16%
12	Not effective	1021	Large	1 (75%)	25%
15	Not effective	177	Large	1	Unknown

3.6. Discussion and conclusion

The results suggest that growth mindsets can be developed in engineering students and that some types of interventions are more effective than others. Within the five studies that had effective interventions, two studies involved repeated interaction with course instructors: study #13, involving interactions with an embedded writing tutor in an engineering course, and study #3, which used the course *Engineering the Mind* to teach topics closely aligned with mindset theory such as neuroplasticity and goal orientation theory. In contrast, the course *On Course* used in the multi-campus, large study #15 had a focus on whole-person learning, including self-efficacy, self-responsibility, and emotional intelligence and was ineffective in developing growth mindsets. The alignment of course instructors to Dweck's (2006) interpretation of 'growth mindset' may have impacted the effectiveness of instructor-focussed studies and this is suggested as a topic for future research.

A number of interventions first introduced students to growth mindsets (through lectures, readings, online tutorials or videos) and then asked students to complete a discussion or writing task. Of these, interventions using online tutorials [#7, 9] were the most effective, followed by interventions using lectures [#4, 14].

Comparing the various scales used to assess mindset, the three-item scale has the advantages of high reliability without the extra work required by use of the eight-item scale. Considering that the original scales were validated with a previous generation of students (Dweck, Chiu & Hong, 1995), mindset studies would benefit from validation studies across different countries, contexts and language translations.

Regarding interventions with low-effect results, we offer four reasons that should be considered by researchers and educators interested in developing and implementing growth mindset interventions. Firstly, engineering students may already start with growth mindsets, as was the case in study #8. Secondly, there may be a trend for engineering students to develop a fixed mindset in their first year, as observed in study #10, particularly in students taking computer science. Interventions may be off-setting the trend towards stronger fixed mindsets. Thirdly, as noted in study #13, students may exhibit growth mindset and fixed mindset traits simultaneously, making it difficult to assess changes in mindsets. Fourthly, beside the follow-up of study #11 that looked at results two years after the intervention, none of the included studies investigated the long-term effects of the growth mindset interventions. We recommend longitudinal studies on growth mindset interventions to track possible benefits that may be missed in shorter studies. Shifting beliefs is often a slow process and most of the included studies reported on results gathered over a semester or a year. Follow-up studies with qualitative data may show that growth mindset interventions are effective over longer time spans.

The application of educational and positive psychology in engineering education for over two decades (e.g. Baillie & Fitzgerald, 2000; Alpay & Ireson, 2006; Sheu et al., 2018; Direito, Chance & Malik, 2019) reflects the growing awareness of how psychological factors affect how engineering students think, feel and act (e.g. Rohde et al., 2019; Yadav, Alexander & Mehta, 2019). Nine of the fifteen growth mindset studies in this review involved other psychology theories and constructs, namely sense of belonging [#1, 11, 12], self-efficacy [#4, 7, 9, 10, 11, 12], grit and persistence [#3, 7], task value [#9, 12], goal setting [#12], affectivity [#4, 10], stereotype disbelief [#7], whole-person learning [#15], perceived competence [#12] and engineering identity [#12]. The trend of researching mindsets along with other topics reflects the interconnectedness of psychology topics in engineering education and research.

Beliefs and behaviour that influence learning are interrelated, multifaceted, sometimes contradictory and can surface under circumstances that may be particular to an individual, which complicate the study of their influence in learning. We support the calls for further research on implementing and assessing multi-topic interventions (Bazelais et al., 2018; Fong et al., 2017) and suggest that engineering education research and practice would be strengthened by expanding the focus of studies that involve beliefs and behaviour to include influences other than individual psychological factors, such as cultural and organisational context (Briody, Wirtz, Goldenstein & Berger, 2019). For example, exploring how organisational mindsets (Canning et al., 2020) can be promoted through collaborative peer-to-peer interactions (Briody et al., 2018), and how students' individual beliefs can affect or be impacted by their team's goals, motivation and behaviour (Murphy & Dweck, 2010). We can then expect that a growth mindset intervention may have different outcomes in a competitive culture where top achievers are rewarded above others versus a co-operative culture where grading is pass/fail. The narrow focus on beliefs from a psychology perspective may be one of the reasons why the growth mindset interventions with engineering students did not produce big changes towards growth mindsets.

In addition, since fixed mindsets may be inadvertently encouraged regardless of teaching approaches (Campbell, Craig & Collier-Reed, 2020), the effectiveness of growth mindset interventions may be negated by contexts which send fixed mindset messages. The influence of the context in which an intervention is implemented may be a reason for the unexpected results reported in Sisk, Burgoyne, Sun, Butler and Macnamara (2018) and in some of the studies in this review. Further research that can provide a measure of the quality of an intervention, possibly through the inclusion of qualitative data, is recommended.

Most studies used quantitative mindset assessment tools (Dweck’s scales), as expected. Quantitative data, as collected by the vast majority of the studies reviewed in this paper, allow for easy comparisons against standardised criteria from which deductions can be made. However, quantitative studies offer limited insight on unanticipated results, such as when a growth mindset intervention yields no significant change. Qualitative data can provide “fascinating and useful insights into student thinking” (Simon et al., 2008, p. 181) that may reveal why interventions are, or are not, successful and “a more holistic understanding of the effort to promote growth mindset” (Dringenberg & Kramer, 2019, p. 1054). Blind-spots, misinterpretations of data collection instruments, and directions for further research can be suggested by qualitative data.

Interventions that increase growth mindsets have been shown to be most beneficial for students from lower socio-economic backgrounds and minority students (Sisk, Burgoyne, Sun, Butler & Macnamara, 2018). If the trend of increasing diversity in engineering courses (Einaudi, 2011) continues, increased positive effects from growth mindset interventions may be realised. Finding subtle ways to target interventions at students who might benefit the most from them, for example, students with lower school GPA’s and lower baseline mindset beliefs (Broda et al., 2018) is suggested for future studies. Not all of the included studies included demographic data to test whether interventions were more effective for sub-groups. However, it is noteworthy that two large studies [#7, 9] with high female participation were effective. Future studies could explore whether interventions are more effective for female students and if growth mindset environments could help to attract and retain female engineering students.

This systematic literature review of growth mindset interventions for engineering students points to a research field that is still developing. Further research - including longitudinal studies, qualitative data and exploring learning in different contexts - can help us to understand the complexities of how to develop and assess growth mindsets in engineering students, particularly for engineering classes with a high level of diversity among students. The variation in effectiveness of these studies supports the idea that mindset interventions should be part of multi-focus strategies to support student success. The range of interventions used in the reported studies provide inspiration for new interventions to incorporate as part of a broader strategy to improve the success of engineering students.

Appendix: Table 3.9 Summary of included studies

#	Study	Research design	Details of intervention	Findings
#1	Broda, Yun, Schneider, Yeager, Walton and Diemer (2018) Reducing inequality in academic success for incoming college students: A randomized trial of growth mindset and belonging interventions. *(Journal article)*	Quantitative. Randomized control study. Pre-intervention survey taken before or during 2-day orientation program, post-intervention survey after 2 semesters. 3-item, 6-point Likert mindset scale and 4-item, 5-point Likert belonging uncertainty scale. Post-intervention variables: differences in grade point averages, course credits attempted, course credits completed, full-time enrolment. Control variables: ACT score, high school grade point average (GPA), Pell grant eligibility, and first-generation status. Participants: 7,686 students, representing more than 90% of incoming first-year students at a large USA Midwestern public university, Michigan State University. 50.3% females, 49.7% males. For growth mindset intervention, students were white (n = 3416), African American (n = 318), Latino/a (n = 193), and other (Asian / Multiracial / unspecified, n = 430). International students (about 15%) were excluded from analysis.	Reading, reflective writing, and writing advice for new students. Online, students read a short scientific article explaining that the brain, like muscles, gets stronger with regular practice, then answered reflective questions, including giving examples of the use of growth mindsets in their lives, and giving advice to future first year students. In the social belonging intervention, students read stories about adjusting to university from the perspectives of senior students at the university and answered reflective questions. The stories were based on focus group interviews with senior students. The first story was selected to be from a student that matched the reader's race and gender. The control condition focused on changes in the physical environment.	No significant treatment effects were found across growth mindset intervention, belonging intervention and control groups, or across the full sample. Pre-intervention mindset means (on a scale of 1 to 6 where higher scores indicate growth mindsets) were 4.74 (mindset intervention group) and 4.77 (control), p=0.21. Post-intervention mindset scores were not reported. Latino/a students who received the growth mindset intervention had significantly higher first-semester GPAs (3.13 vs 2.73 on a scale of 0 to 4, p<0.01), 2nd semester GPAs (2.97 vs. 2.64, p<0.02) and 1st year cumulative GPAs (3.05 vs. 2.69, p<0.002) than their peers in the control group.
#2	Calisto (2013). Effects of using word problem malleability primes on students. *(PhD Dissertation)*	Quantitative. Quasi-experimental, non-randomized, pre- and post-test control group design. Dependent variables: mindset scores from a 3-item, 6-point Likert mindset survey, math performance on a 10-question class activity, and the number of hard as compared to easy math questions attempted by students on a 30-question challenge activity. Pre-	Growth mindset messages were included in word problem activities given to students in university mathematics courses in an 8-week semester, e.g. *Sonya read 72 pages of "Math Intelligence: With Hard Work and Effort You Can Increase It"* versus neutral problems for a control group,	Most participants (44 out of 54 with full data sets) had growth mindsets initially, with mindset mean scores of 4.79 (intervention group A) and 4.83 (intervention group B) on a scale from 1 to 6 where scores of 4 and above represent growth mindsets and scores of 3 and below represent fixed mindsets. No significant changes were observed for

		intervention survey given to 2 groups in each of 9 classes in week 2, then groups alternated doing intervention or control activities in weeks 3-5 and weeks 6-8. Participants: 73 non-traditional, Hispanic-, African-, and European-American students, aged 18 to 58 (average age 27) in an 8-week *Fundamentals of Mathematics* or *College Algebra* course at two separate campuses of a USA Midwestern career college.	e.g. *Sonya read 72 pages of her favourite book.*	students' mindset beliefs: post-intervention mindset scores were 4.60 (intervention group A) and 5.19 (intervention group B). Students' performance on a 30-item challenge activity and 10-item mathematics quiz decreased between pre-test and a post-test three weeks later.
#3	Choi (2018). Grit, mindsets, and persistence of engineering students. *(PhD Dissertation)*	Mixed methods. Pre- and post-course survey on mindsets (8-item, 6-point Likert scale), goal orientation (14 items), and self- regulation (20 items). Qualitative data: Reaction papers of thoughts on TED Talks and other media assigned as homework, reflection papers on course topics and activities, strategy documents to plan and evaluate weekly academic goals. Participants: 15 college of engineering students at a large public university in the Western USA, 3 females, 12 males, 4 in 1st-year, 3 in 2nd-year, 6 in 3rd-year, 1 in 5th year, 1 in 6th year.	The mindset intervention was participation in the course *Engineering the Mind* designed to increase growth mindsets. Design-based research and the Transtheoretical Model of Health Behaviour Change were used to guide the translation of theories related to healthy learning dispositions and behaviours into the design of the *Engineering the Mind* course. Course topics included neuroplasticity, mindsets, goal orientation theory, self-regulation.	Large, matched-pairs rank-biserial correlations were r = 0.90 and –0.80 for growth and fixed mindset, respectively, showing that the course Engineering the Mind increased growth mindsets and decreased fixed mindsets. Large effect sizes were calculated for growth and fixed mindset: 0.54 and 0.48, respectively. High reliability of the mindset scales was suggested by Cronbach's alpha values of 0.89 and 0.96 for the growth mindset and fixed mindset items on pre- and post-surveys, respectively.
#4	Cutts, Cutts, Draper, O'Donnell and Saffrey (2010). Manipulating mindset to positively influence introductory programming performance.	Quantitative. Pre- and post-intervention survey measuring mindset, self-efficacy and positive and negative affect. Survey given in weeks 1 to 7 of a first-year computer programming course in the UK. Participants: 89 out of 170 students completed both surveys. Tutor groups of 9 to 17 students. Demographics and survey details not reported.	Three-part intervention in weeks 1 to 7 of year course: Lecture and reflection; crib-sheet; feedback sheet. (1) Four 10-15-minute tutor talks about an aspect of growth mindsets and then a reflective exercise focusing on students' own learning experience and relating it to mindsets. (2) Crib-sheet of what to try if your computer programme fails, to encourage using different strategies rather than the	In the first week, 19 (21%) of the students displayed a fixed mindset, 38 (43%) a growth mindset and 32 (36%) neutral mindsets. The crib-sheet intervention did not affect mindset and test scores. Teaching about mindsets shifted students towards growth mindsets but did not impact class test scores. Between weeks 1 and 7, average mindset scores for students in the mindset training intervention increased

	(Conference paper)		fixed mindset trait of repeatedly trying the same inappropriate strategy. Half a lecture spent explaining the purpose of the sheet. Tutors answered all student questions with reference to the crib sheet. (3) Adding this text to feedback sheet on fortnightly assignments, "Remember, learning to program can take a surprising amount of time & effort – students may get there at different rates, but almost all students who put in the time & effort get there eventually. Making good use of the feedback on this sheet is an essential part of this process."	from about 3.71 to 3.93 (on a scale presumed to be from 1 to 6 where higher scores indicate growth mindsets) while mindset scored for the control group decreased from an average of 3.62 to 3.39, indicating a significant difference between intervention and control groups (F(1,75)=4.18; p<.044). There were two-way interactions with mindset training and rubric interventions on both the first test and final exam.
#5	Dringenberg, Shermadou and Betz (2018). Reactions from first-year engineering students to an in-depth growth mindset intervention. *(Conference paper)*	Qualitative. Exploratory and interpretive. Researchers developed codes for emergent themes based on line-by-line analysis of online written discussions on NVivo. Inter-rater reliability was assessed using the kappa statistic. Participants: 8 first year students in a general engineering program at a large, public, Midwestern University, USA.	Reading group with 2 researcher-participants and 8 students meeting online on the university's learning management system for five one-hour sessions in a semester. In each session they discussed their reading of 1-2 chapters of Dweck's (2006) book *Mindset*, responding to 2-3 written discussion prompts adopted from *Mindset*. [Same as second intervention in Dringenberg and Kramer, 2019.]	Students reconsidered past interpretations of experiences and projected forward on possible changes towards a growth mindset. Students understood that growth mindset "was not an all or nothing switch to be flipped." In data coding, the researchers achieved moderate agreement for the subthemes of *Reinterpreting Past Experiences through the Lens of Mindset—Fixed Mindset* (kappa value of 0.50) and *Growth Mindset* (kappa value of 0.59). For the second theme, *Projecting a Future Utilizing Growth Mindset*, the researchers received a fair agreement (kappa score of 0.25).
#6	Dringenberg and Kramer (2019). The influence of both a basic and an in-depth	Mixed methods. Pre- and post-semester survey with 4-item, 7-point Likert mindset scale and items on engineering design self-efficacy and orientation to the field of engineering. Independent	Two interventions over one semester: Intervention 1: 30-minute introduction to growth mindset theory in the second class of the semester included students self-assessment of	Neither the in-class introduction nor the more in-depth intervention had a statistically significant influence on students' mindset beliefs. On 1 – 7 scale where higher values indicate growth

	introduction of growth mindset on first-year engineering students' intelligence beliefs. *(Journal article)*	variables included sex, ethnicity, race, prior experience with engineering, first-generation status and engineer parent/guardian. Qualitative data: written reflections about motivations to study engineering, experiences with engineering problem solving and perspective of own intelligence and how their fixed or growth mindsets will impact students' pursuit of an engineering degree. Participants: 1st-year students in a general engineering program at a large, public, Midwestern USA university. 72 students participated in the first intervention, 6 of these students went on to join the second intervention.	their mindsets, an overview of mindset characteristics, research findings on the benefits of growth mindsets, a short video on grit, a think-pair-share discussion on student's own mindsets, and encouragement to promote growth mindsets in individual and team work. Intervention 2: Students were invited to join a mindset reading group that met online, outside of class time, for 5 hour-long sessions to discuss their reactions to the theory.	mindsets, the in-class introduction had pre-survey mean of 5.22 and a post-survey mean of 5.40. The in-depth intervention had a pre-survey mean of 5.17 and a post-survey mean of 5.50. The in-depth intervention did provide students with a more nuanced understanding of growth mindset theory. A brief introduction into mindset theory is not adequate for significant change in beliefs. Survey items alone may not be indicative of growth mindset and qualitative approaches may be necessary for researchers to gain a more holistic understanding of students' intelligence beliefs.
#7	Fabert (2014). Growth mindset training to increase women's self-efficacy in science and engineering: A randomized-controlled trial. *(PhD Dissertation)*	Quantitative. Randomized control study. No pre-test to conceal the true purpose of the intervention from participants. Post-intervention survey given immediately after intervention. Random allocation to control, treatment and comparison groups following an online demographic survey of age, gender, racial/ethnic background, country of origin, SAT or ACT score, exploratory track, and class standing. Variables: 3-item, 6-point Likert mindset scale (self-form), stereotype disbelief, STEM self-efficacy, intentions to pursue STEM disciplines, number of college courses completed and enrolled for. Participants: 298 women and 191 men in a "Choosing a major" course at Arizona State University, USA, 5.5% African American/Black; 7.4% Asian American/Pacific Islander; 60.5% White; 14.5% Latina/o; 2.2% Native	An online growth mindset tutorial and letter writing assignment, completed in under an hour, started in the second face-to-face class meeting. Completion of the online 'pen-pal writing' intervention or alternative contributed 5% of class grades. Students were told to allocate 1.5 hours to completing the task.	At post-test, treatment group mean mindset scores (4.75) were significantly higher ($p < 0.001$) than the mean mindset scores of both comparison (4.19) and control groups (4.20), where scores range from 1 to 6 and higher scores indicate growth mindsets. Average GPAs of treatment group participants (3.10) were significantly higher than those of control group participants (2.86) but not those of comparison group participants (3.03). Growth mindset belief and stereotype disbelief were positively related ($r = 0.36$, $p < 0.001$); growth mindset belief was positively related to men's STEM self-efficacy ($r = 0.22$, $p < .001$).

		American/Alaskan Native/ Hawaiian; 6.1% Multiethnic/Multiracial, 3.7% undeclared. Ages 17 to 27, 85% were 18 years old at the time of the study, 98% in 1st year. 100 students on an "Engineering, Math, Technology, & Physical Sciences" exploratory track.		
#8	Frary (2018). Encouraging a growth mindset in engineering students. *(Conference paper)*	Mixed methods. Pre- and post-course online survey on Google forms including open-ended questions and a 16-item, 7-point Likert mindset scale. Variables: gender, high school graduation year, paths to Boise State University. Participants: 26 students enrolled for a semester course, Thermodynamics of Materials, taken in the second last year of an engineering degree at Boise State University, USA. 20 males, 6 females, 14 students were at most 3 years out of school, 5 students were 4 to 9 years out of school, 7 students were more than 10 years out of school.	Four-part intervention. In week 1, students watched Carol Dweck explaining growth mindsets on TedTalk and Khan Academy videos, followed by class discussion. In weeks 4, 9 and 13 students read articles on growth mindsets and wrote answers to questions. At the beginning of class each day, the instructor shared a growth mindset quote with the students. How quotes related to students' learning and experiences in the course were discussed a few times throughout the semester.	50% of students shifted to a stronger growth mindset post-intervention. Students already had growth mindsets to begin with. At the beginning of the semester, 8 students had strong growth mindsets and 14 more had growth mindsets with some fixed ideas. At the end of the semester, 10 students had strong growth mindsets and 14 more had growth mindsets with some fixed ideas. Greater shifts to growth mindsets were noticed in students who had been out of high school for 10 or more years. Post-course, more students described "intelligence" through a growth mindset lens instead of a fixed mindset one.
#9	Hoang (2018). Growth mindset and task value interventions in college algebra. *(PhD Dissertation)*	Quantitative. Randomized control study. Pre- and post-intervention survey on mindsets (3-item, 7-point Likert modified to ask about mathematics intelligence), self-efficacy and value perceptions, given in weeks 7 to 13 of a semester course. Demographic data: gender, age, year of study, ethnicity, race, mother and father's highest education level, developmental courses taken. Post-intervention course grades collected. Participants: 426 students in four sections of a College Algebra course in a large, public	Intervention or control activities in week 9 or 10 and week 11 or 12 in a 13-week semester course. For the growth mindset intervention, students read online about brain growth during learning and wrote a reflection on a time when they strengthened their neural connections in mathematics. Then they read about how effort and appropriate strategies can help in learning mathematics, and the benefits of a growth mindset, and summarised the information in a letter to a future	Even after controlling for demographics, course sections, pre-survey scores, and test 1 scores, participants in the growth mindset group ($b=.235$, $SE=.097$, $p=.035$, $d=.235$) had significantly higher post-survey intelligence beliefs than the control group, confirming that the growth mindset worked in changing intelligence beliefs. Pre-intervention mindset scores on a scale of 1 to 7 where higher scores indicate growth mindsets were 4.81, $sd=1.35$ (intervention) and 5.11, $sd=1.33$ (control); post-intervention mindset

		university in the Southwestern United States, 79.1% female, aged 18 to 32 (M=18.56; SD=1.43); 40.1% Hispanic, 39.0% White, 13.6% Black, 7.3% other races/ethnicities; 82.6% in 1st year, 11.0% in 2nd year, 4.9% in 3rd year, and 1.4% in 4th year; 39.9% first-generation students; 5.9% previously took developmental mathematics.	student. For the task value intervention, students rated reasons why college algebra could be useful to them, wrote a letter to future college algebra students on why learning college algebra was personally relevant to them, and wrote a reflection about whether learning college algebra could be beneficial to others. For the control activity, students completed 10 mathematics questions suggested by instructors.	scores were 5.13, sd=1.52 (intervention) and 4.93, sd=1.33 (control).
#10	Reid and Ferguson (2014). Do design experiences in engineering build a 'growth mindset' in students? *(Conference paper)*	Quantitative. Non-randomized control study. Pre- and post-course 27-item mindset scale. In a year prior to this study, mindset scores for 84 1st- year engineering students were taken at the start, middle and end of an academic year. Comparisons of mindset score trends were made between this previous-year group and the study intervention and control groups. Participants: Students at a large, Midwest USA College of Technology taking a 1st-year design-oriented *Introduction to Engineering* course. Control group students were taking a 1st-year course that had no significant open-ended design project. (Number of participants not given.)	Open-ended design project in weeks 8 - 12 of a two-semester *Introduction to Engineering* course.	No significant increase in growth mindsets. While control students showed a slight shift to having stronger fixed mindsets (growth mindset mean 3.54 to 3.44 on a scale presumed to be from 1 to 6 where higher scores indicate growth mindsets; fixed mindset mean 2.70 to 2.78 where higher scores indicate fixed mindsets), intervention students showed little change (growth mindset mean 2.89 to 2.87; fixed mindset mean 3.15 to 3.11). Mindset scores for a previous year showed a slight, non-significant shift towards fixed mindsets from start of year to end of year (mean for growth mindset items 3.36 to 3.28; fixed mindset items mean 2.74 to 2.83).
#11	Rhee, Johnson and Oyamot (2017). Preliminary findings using growth mindset and belonging interventions in a	Quantitative. Randomized control study. Pre- and post-intervention surveys in first and last weeks of a 16-week semester. 3-item, 5-point Likert mindset scale. ANCOVA tests with cumulative GPA and units completed as dependent variables, high school GPA and SAT as covariates.	Reading and reflective writing in week 8 of a 16-week semester. Students were assigned to a control, growth mindset or belonging group. The growth mindset group read an article comparing the brain to a muscle that gets stronger with regular practice.	Before the interventions, under-represented minorities (URMs) had higher growth mindset scores than non-URMs. After 1 year: among women, the growth mindset intervention correlated with lower course performance compared to

	freshman Engineering class. *(Conference paper)* Rhee and Johnson (2019). Progress on longitudinal study of the impact of growth mindset and belonging interventions in a freshman engineering class. *(Conference paper)*	Chi-square tests to determine if interventions impacted retention. Block randomization by section, in which gender, under-represented minorities (URM)/non-URM, and Pell-eligibility were distributed across conditions as equally as possible. Participants: 441 first-year students in a required Introduction to Engineering course at San Jose State University, USA. 24 students had not declared engineering as a major, about 16% female, at least 18 years old, Asian (39%), Hispanic (21%), and White (20%). 5 semesters of retention and progress-to-degree data for 435 students were analysed in the 2019 paper.	The belonging group read excerpts from fictional seniors of various ethnicities and genders describing their integration into the university. Each group wrote a reflective essay in one of thirteen course assignments. The normal course reflection assignment was assigned to the control group.	the control and belongingness groups; among men, the belongingness intervention correlated with higher course performance than in the growth and control; the interventions did not differentially affect course performance among URMs. After 2 years there was no effect of either the growth mindset or the belonging intervention on academic performance, units completed, or retention. After 2 years, for non-Pell-eligible students, retention rates were trending towards significance: Control, 88.0%, Belonging, 93.1% and Growth Mindset, 96.7%. After 2 years the average change of major to engineering were: Control, 83.3% (5 out of 6); Belonging, 81.8% (9 out of 11), and Growth Mindset, 85.7% (6 out of 7).
#12	Robinson (2019). Supporting multiple paths to success: A field experiment examining a multifaceted, multilevel motivation intervention. *(PhD Dissertation)*	Quantitative. Randomized control study. Pre- and post-intervention surveys including 8-item, 6-point Likert mindset scale. Outcome variables: Motivation (values, achievement goals, perceived competence), engineering identity, course grade, GPA, engineering major retention. Interactions with prior achievement (mathematics placement test scores from university records) were also examined to determine whether the intervention effects were stronger for low-achieving students. Participants: 1,021 students in an undergraduate, introductory course required for engineering majors at a large, USA Midwestern university, 75% in 1st	Three interventions over one semester. In the mindset intervention, students viewed and responded to video content explaining how the brain builds connections over time and in response to experiences. In the belonging intervention, students viewed video clips of older students who described experiences of adversity in college and how those experiences had been common among first-year students. Students answered comprehension questions after each video and used the concepts they had learned to write a letter to a future student who might be struggling. The third intervention asked students at	Over one semester, no significant difference in mindset was found between the mindset intervention and control conditions (Wilks' λ (386, 2) = .99, p = .12, partial η^2 = .011). Overall, there were no statistically significant effects of either intervention on the outcome measures, (motivation, engineering identity, course grades, GPA, engineering major retention) compared to control conditions, and no significant moderating effects based on prior achievement.

		year, 24.9% female; 78.4% white, 13.4% Asian/Asian American, 1.9% African American, 3.5% Hispanic/Latino, 2.8% Multiracial; and 11.3% first-generation college students.	three times in the semester to write 200-word essays explaining the relevance to their own lives of a concept learnt that week.	
#13	Schubert (2017). Exploring the connections between students' mindsets and their writing: An intervention study with a course-embedded writing tutor. *(PhD Dissertation)*	Mixed methods. Pre- and post-intervention surveys using an 8-item, 6-point Likert modified mindset scale with 3 additional questions on talent versus effort. Interviews with students and the embedded writing tutor coded using an inductive approach. Researcher rating of students' first and final drafts of literature reviews to see if growth-minded students revise drafts substantially or perform at a higher level. Participants: 57 engineering students in a writing course at a rural public research university in the USA.	An experienced writing tutor, trained in mindset theory and employed by the University Writing Center, was embedded in a semester course taken by engineering students. The tutor's two tasks comprised the intervention: (1) give an in-class lesson on growth mindset theory and (2) consult with students individually to give them feedback on their literature review drafts.	Data from 36 students who completed pre- and post-intervention surveys showed that students who received the embedded tutoring intervention improved their mindsets more significantly than students in the control and comparison groups. (Values not available.) In addition to becoming more growth-minded, these students' final drafts were also substantially better in terms of organization, style, and mechanics.
#14	Simon, Hanks, Murphy, Fitzgerald, McCauley, Thomas and Zander (2008). Saying isn't necessarily believing: Influencing self-theories in computing. *(Conference paper)*	Mixed methods. Control study. Pre- and post-course survey, 6-item, 6-point Likert mindset scale comprising 3 stand-alone items from Theories of Intelligence Scale-Self Form for Adults, 2 items from Dweck's (2000) Questionnaire Goal Choice Items to assess whether students are more concerned with performance or with being challenged in their courses, and 1 item by authors to determine if students viewed programming ability differently from general intelligence. Spearman's rank correlation coefficient calculations checked which statements had the potential for significant correlations. Focus group with 6 students to discuss interpretations of the 3 Theories of Intelligence Scale items. Open-	Mid-way through a semester-long computer science course, students were given a 10-15-minute lecture on a fixed mindset vs. growth mindset diagram that compared challenges, obstacles, effort, criticism, and the success of others. One week later, students were given a one-page reminder of lecture and asked to write advice for new students, describing a time when they learnt something new other than programming, being specific about the kinds of mistakes they made and how they overcame them, and advising a beginning programmer, emphasizing how they can grow their programming intelligence through dealing with	Mixed results among groups. Spearman's rank correlation coefficient (ρ) calculations showed that only the 3 items from Theories of Intelligence Scale had the potential for significant correlations (ρ = 0.48, 0.55 and 0.28 for statements 1&2, 1&3 and 2&3, respectively). Some statistically significant changes for survey item responses were evident across intervention groups but not all in the same direction. For example, for the two fixed mindset items from the Theories of Intelligence Scale, pre- to post-intervention mean scores (on a 1 to 6 scale where higher values indicate growth mindsets) were 3.57 to 4.29 (p = .033, intervention B), 3.66 to 3.28 (p =

		ended 'explain your choice' questions in post-course survey. Participants: 228 mostly 1st year students in Computer Science 1 courses across 3 institutions: a small, private, liberal arts university located in the United States (n = 19, intervention group A), a larger university located in the United Kingdom (n = 28, intervention group B), a large North American research-extensive university (n = 84 in intervention group C, n = 97 in control group).	programming challenges. The control group had a lecture on learning styles and were asked to write about learning styles.	.004, intervention C) and 3.76 to 3.53 (p = .011, control). In a survey in a follow up course, students did recall the intervention but did not think it changed their mindsets.
#15	Willeke (2015). Relationship between whole-person learning and growth mindset in first-generation learners. *(PhD Dissertation)*	Quantitative. Pre-test, post-test, control group, quasi-experiment design. Independent variable: enrollment in a semester-long orientation course, *On Course*. Online pre-test survey in week 1, post-test in last week. Dependent variable: 8-item, 5-point Likert mindset scale. Demographic data: Age, gender, ethnicity, whether parents have attended college, whether parents have completed college, employment status, location. ANOVA on mindset, age, gender, race. Participants: 177 first-year, first-generation students taking *On Course* at one of four community colleges in the USA, 18 years or older.	Exposure to whole-person learning through the orientation course *On Course* curriculum that includes many aspects of whole-person learning, which was hypothesized to develop growth mindsets.	Matched pairs of pre-test and post-test data for 35 students in the intervention and 2 students in the control were too few for within-subjects comparative analysis. No significant difference was found between mindset means for the pre-test (intervention mean = 60.95, sd = 10.02, n = 85; control mean = 64.88, sd = 8.31, n = 18) and post-test (intervention mean = 61.09, sd = 10.46, n = 61; control mean = 65.23, sd = 11.26, n = 13) on a scale from 16 to 80 (where higher values indicate growth mindset). An ANOVA analysis showed that the *On Course* curriculum did not have a significant effect on the mindset score for first-generation students over the duration of a first-year orientation course. Black first-generation learners had a significantly higher growth mindset mean score (67.94) than white first-generation learners (60.81) in the post-test.

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3.7. Reflection

The results from this systematic literature review show that the most common intervention design for developing engineering students' mindsets was to teach students about mindsets and then have students share their reflections or advice with other students. My objective was to build on this intervention design to develop and test an intervention in which students share mindset advice and their experiences in a social media community. This plan required well-functioning tutoring groups on the social media platform WhatsApp. Chapter four describes how successful group functioning was achieved through the application of design-based research.

Chapter 4: Design-based research

4.1. Chapter introduction

The theoretical framework in chapter two established how growth mindsets and, inadvertently, fixed mindsets can both be encouraged regardless of the learning theories that drive educators' responses to students and their design of learning activities.

The literature review in chapter three showed that the most common intervention for developing growth mindsets was providing students information about mindsets and how learning occurs, followed by tasking students with reflecting on or teaching-on the ideas, for example, through writing a letter to encourage a new first-year student who had received a low assessment for a task.

Informed by the mindset interventions described in the literature review, I intended to use a teach-on intervention to encourage growth mindsets in engineering students who volunteered as tutors to high school students on the social media platform WhatsApp. While establishing the tutoring groups and data capture, it emerged that the groups were not functioning as anticipated. This spurred a design-based research project to establish well-functioning tutoring groups, which is the subject of this chapter.

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4.2. Abstract

Social media platforms such as WhatsApp are increasingly used in formal education settings. However, there is little research to guide educators on how to set up effective peer tutoring groups on social media platforms, particularly between tutors and tutees who rarely meet face-to-face. In the context of a WhatsApp mathematics tutoring project, we present evidence-based principles to guide the establishment and operation of peer tutoring groups on a social media platform. The development of the principles followed a design-based research framework, based on theories about peer learning, participation barriers to social media use in a low socio-economic setting, and input from participants, who were high school students and university students in Cape Town, South Africa. The refined principles provide guidance for others in similar settings who aim to use tutoring groups on a social media platform to achieve education goals.

Keywords: Design-based research; social media; student learning; peer tutoring; peer learning; constructivism; WhatsApp; m-learning; e-learning; blended learning; mathematics.

4.3. Introduction

Mobile internet technology has disrupted learning and teaching contexts (Bozalek & Ng'ambi, 2015) by enabling students to control access to text and human resources. Social media platforms such as WhatsApp are increasingly used as part of formal education programmes (Tess, 2013; Tang & Hew, 2017; Rambe & Mkono, 2019), and can support peer tutoring (Samaie, Mansouri Nejad, & Qaracholloo, 2016) and learners in low resource settings (Pimmer et al., 2019). However, educator-level and institution-level challenges work against the integration of interactive technology in education settings (Ohei & Brink, 2019).

This study is a response to calls for research on the drivers and enablers of social media use and the barriers to the effective use of social media (Rambe & Nel, 2015). Following a design-based research approach (Reeves, Herrington & Oliver, 2005), we present principles for setting up peer tutoring groups on a social media platform in a South African context, where face-to-face contact between high school student tutees and their university student tutors was infrequent. Refinement of the design principles was informed by participants' responses to questionnaires and interview questions, and project developers' reflections on their own diary entries. Finally, we compare the participation in peer tutoring groups before and after implementing the refined design principles.

4.4. The WhatsApp Mathematics Tutoring Project

Inspired by a mobile learning project that provided fee-free homework help for high school students (Botha & Butgereit, 2012), a WhatsApp mathematics tutoring project was devised to provide anywhere, anytime, fee-free mathematics help to high school students from Cape Town townships. Volunteer tutors were engineering students. High school students were from the 100-UP school outreach programme at the University of Cape Town (Silbert, Clark & Dornbrack, 2015).

Groups of up to five high school students (tutees) were linked to one or two tutors in a WhatsApp chat group. Tutees asked tutors mathematics questions when they were stuck on homework problems. Tutors responded with explanations and leading questions. To encourage communication in the group, weekly messages were sent by a project manager to tutors to share with tutees. The messages included a challenging mathematics question, study tips and encouragement of aspirations to attend university.

4.4.1. Quality assurance

Agreement to have chats recorded and anonymously shared was a precondition for joining the WhatsApp mathematics tutoring project. This allowed the interactions to be monitored by a project manager for quality control.

When tutors were challenged by difficult mathematics questions, they could look up online definitions and examples, or use sophisticated online calculators like symbolab.com and wolframalpha.com, or ask their network of peers. A WhatsApp group for tutors allowed for easy connection between tutors for advice on answering questions from tutees.

4.5. Peer tutoring

While peer tutors are typically more advanced than tutees in some way, peers are characterised by having the same social standing (Colvin, 2015), sharing age, status and/or ability. Tutees and tutors in this project were near-peers as tutors were at least one year older than tutees, and tutees were still striving to achieve entry to university.

4.5.1. Benefits from peer tutoring

As well as gaining a better understanding of an academic topic, peer tutoring benefits both tutors and tutees through the development of psychosocial attributes and communication skills (Bean & Eaton, 2001-2002).

Feedback from others and a growing consciousness of their participation in peer tutoring interactions can increase students' sense of self-worth (Falchikov, 2007), and develop self-monitoring and self-regulation, leading to greater self-esteem and self-confidence (Topping & Ehly, 2001). Tutees can experience increased motivation towards learning when they see themselves as being groomed as future tutors (Topping, 2005), and when they play the role of a tutor through sharing insights from peer tutoring sessions with peers not in the tutoring group.

Peer tutoring can develop communication skills through the demanding exercise of changing thoughts into words and the practice of reading, questioning, summarising and explaining (Boud, Cohen & Sampson, 2014). These transferable skills can help students in other learning areas. Shy or neuro-atypical participants may find communication easier online (Arasaratnam-Smith & Northcote, 2017), especially as the use of a social media platform like WhatsApp allows students to feel free to use abbreviations, slang, alternative spelling and emojis (Keogh, 2017). The use of familiar discourse in communications may facilitate bonding between group members.

A trust relationship with a peer who is not responsible for grading the interaction may help participants to expose their knowledge gaps and misconceptions and learn more (Liu & Carless, 2006). Just-in-time responses may help students persevere when struggling, increasing time spent completing work, which is associated with stronger performance (Babaali & Gonzalez, 2015).

4.5.2. Participation barriers to peer tutoring on social media

Research on internet access in low-income areas has shown that access to devices is not the main barrier to social media use, rather it is the cost of internet connectivity via cellular network providers (Rivera-Sánchez & Walton, 2013). South Africa has one of the highest costs of mobile data in the world (Brown, 2018) but free or low-cost internet access is increasingly available (Western Cape Government, 2018). The low cost of communicating on WhatsApp contributes to its popularity with students from low socio-economic areas (Nyasulu & Chawinga, 2019) and makes WhatsApp ideal for academic interactions in the South African context (Rambe & Mkono, 2019).

While tutees have personal mobile phone numbers, they may share a device with family members and switch SIM cards to access personal messages (Walton & Leukes, 2013). Tutees may appear to have left their WhatsApp tutoring group when their SIM card is disconnected from the mobile network and may need to request to re-join the group frequently. The full chat history may not be available to students who keep leaving the group, increasing feelings of isolation.

Communicating using mathematical symbols can be challenging if photographs or video clips are not able to be used due to the functionality or storage capacity of the device, or the cost of sending and receiving data. However, Botha and Butgereit (2013) showed that students communicating using mathematical symbols on the platform Mxit, where typing was the only option, were able to type mathematical expressions on mobile phones and make themselves understood.

4.6. Design implications from learning theories

It has been argued that a single theory of learning is insufficient to explain how people learn (Sfard, 1998). A helpful tool for determining which of six learning theories dominate in a mobile learning setting is a set of tables presented by MacCallum and Parsons (2016). Using these tables, we judged that the theories of constructivism, connectivism and communities of practice aligned most strongly with peer tutoring in mathematics on a social media platform. In the next section, we briefly discuss key implications for the design of peer learning on a social media platform from the most closely aligned theory, constructivism. In Table 4.1 we present constructivist criteria from MacCallum and Parsons (2016) with descriptions of how peer tutoring in mathematics on a social media platform addresses the design implications.

4.6.1. Implications from constructivism for peer tutoring on social media

The emphasis in constructivism is on an individual *creating* rather than *acquiring* meaningful knowledge. In a constructivist framework, tutors should be encouraged to help students create meaningful knowledge rather than just providing answers. For example, sending the first line of a solution or asking leading questions nudges students to create meaning. In contrast, posting full answers to homework questions for students to read through is a way for students to acquire knowledge.

Participants should feel that their tutoring group is a safe space where noticing and correcting errors and misconceptions is valuable to learning and is encouraged. The value of mistakes for learning can be promoted by tutors encouraging shy students to privately ask questions. The questions and responses can later be posted to the group without revealing who first asked the question. To provide the social mediation needed for the tutee to learn, a tutor needs to understand the tutee's current level of understanding (Vygotsky, 1978).

The learning design implications for constructivism presented by MacCallum and Parsons (2016) fit with the goals of the WhatsApp mathematics tutoring programme. Table 4.1 lists the criteria that would identify an approach as constructivist with corresponding applications to peer tutoring on a social media platform.

Table 4.1: Constructivist criteria and design applications for social media peer tutoring groups

Constructivist criteria (MacCallum & Parsons, 2016)	**Application to peer tutoring on a social media platform**
1. Learning should be an active and meaningful process.	1. Encourage high activity (asking and answering questions) rather than low activity (reading posts but not commenting). Some social chatting can help to make the group meaningful on a personal level for participants. Keep the focus on topic with a sign-up form that requires agreement for chats to be recorded and potentially used (anonymously) for research. For tutors, revising content topics in preparation to help someone adds meaning to revision.
2. Learners should construct their own knowledge rather than accepting that given by the instructor.	2. Ask tutees to supply or rephrase definitions, where possible. Assure students that mistakes can be made by tutors (and teachers) and encourage mistake-spotting.
3. Collaborative and cooperative learning should be encouraged to facilitate constructivist learning.	3. Encourage tutors not to be quick to give full solutions but to help students to solve problems themselves, where feasible, with input from other group members. Seeing the questions and responses from other students can help students learn from other's mistakes.
4. Learners should be given control of the	4. Social media chats may be in real time or there may be delays between questions and responses,

learning process and time and opportunity to reflect.	according to the constraints on tutors and tutees. If SIM cards remain in devices, the record of chats can be revisited.
5. Learning should be interactive to promote higher-level learning, personal meaning, awareness of others, and a sense of belonging.	5. Social media is highly interactive. Tutor responses have personal meaning to students who ask questions. Tutoring is personally meaningful to tutors who have volunteered to help others. Tutees can be encouraged to think of becoming tutors themselves in the future.

4.7. Method for refining design-based research principles

Initial principles for the design of the WhatsApp mathematics tutoring project were developed from Topping and Ehly's (2001) five categories that influence the effectiveness of peer tutoring: organization and engagement, cognitive conflict, scaffolding and error management, communication, and affect. Design principles were refined over the first two years, based on survey and interview responses from university student tutors and high school tutees, and reflections on diary entries by the project developer and two research assistants. An assessment of the design principles and further small adjustments were made following focus group interviews with tutors in the third year.

4.7.1. Data collection

Surveys on preferences were sent to tutors (online) and tutees (on WhatsApp) prior to the formation of the groups in year one. Separate focus group interviews with tutors and tutees took place in months five and ten of year one and month eleven of year two.

The project developers (a lecturer and two undergraduate research assistants) wrote individual journal reflections on the project during year one. Each author reflected on their journal entries and looked for themes that emerged. In face-to-face meetings, personal reflections on the journal entries were discussed and compared to improve inter-rater reliability. In year two the project developer wrote reflective journal entries after meetings with new research assistants.

4.7.2. Ethics

A condition for joining the online tutoring project was to accept that all WhatsApp communication would be recorded and used anonymously for research. Students could ask for partial or complete withdrawal of their data from the study up to the time of data analysis but none did. A written explanation of the project was sent to participants on WhatsApp. Students requiring parental consent were encouraged to verbally discuss the project with their parents/guardians, some of whom did not read English, so that there was an understanding that conversations would be recorded and could be anonymously published.

All identifying details (real names, nicknames, mobile phone numbers and identifying images) were replaced with codes to preserve anonymity. Ethics approval was obtained from a research ethics committee at the tutors' university prior to the start of the project.

4.8. Findings from data collection

4.8.1. Tutee surveys

Tutees were asked their preferences for language use, times for WhatsApp chats, and preferred group members. The low response rate of 34% (14 out of 41 tutees) may indicate that tutees did not have strong preferences for the set-up of the groups. Most tutees spoke isiXhosa as a home language. Ten tutees preferred a group where they could use both English and isiXhosa, three preferred an English-only group and one an isiXhosa-only group. Ten students preferred communicating with a tutor from 4:30 p.m. to 6:30 p.m. Only four students (all females) specified names of preferred group members, while ten selected the option of 'any' group members.

4.8.2. Tutor surveys

All the initial sixteen tutors (five females, nine males) responded to the survey on preferences for tutoring groups. Nine tutors (three females and six males) preferred having their own tutoring group; two female students and five male students preferred to tutor in a group with another tutor. Eight male tutors preferred tutoring groups with mixed-gender groups, none wanted an all-male group, and all-female groups were preferred by one male and one female tutor. Tutors' preferred times for communicating with tutees mismatched those of tutees: only four tutors preferred communication times before 8 p.m. The most popular time chosen by the other ten tutors was 8 p.m. to 9 p.m.

4.8.3. Tutee interviews

In focus group interviews after the first five months, the most pressing issue for tutees related to affect and group composition. The request, "Please, we want people from other schools [to join the group]" was enthusiastically supported by other tutees in a focus group interview. When asked about potential confusion if different schools covered mathematics topics at different times, tutees said this was "no problem" because the pacing of content would be similar, and they could return to view chats if they were initially unable to understand the content of chats.

The social aspect of the groups appeared to be highly motivational to the tutees. Tutees expressed great interest in having occasional face-to-face meetings with tutors.

4.8.4. Tutor interviews

A common problem was tutees "dropping off" the tutoring group. Sharing phones with family members and using multiple SIM cards (to get the cheapest deals) explained some of the dropout, but tutees sometimes wanted to join a friend's group, especially when they perceived the group to be more active. Where several tutees were inactive, tutors felt that the group size could grow to ten. If a group's activity became overwhelming for a tutor, it was suggested that the group could split and some students join with another tutor with unresponsive tutees.

Even when groups were stable, tutees were reluctant to ask questions in the group. Tutors were concerned that asking a question that peers will see may be more intimidating in a larger group. A tutor suggested, "Tutees might think, 'We're too many, he won't notice [my silence].'" More one-to-one contact between tutor and tutee was seen as important in order to develop trust so that tutees felt more comfortable asking questions.

Another difficulty noted by tutors was the lag between questions and responses, particularly if the response required interaction with the tutee. A tutor reported that if a response wasn't given within four to five hours, tutees would not seem interested in the response when it came, "they would drop it."

It was suggested by tutors that school vacations would be a good time to engage in a more intense way by working through past examination papers. Tutees would not have access to teachers during holidays but could be encouraged to work in groups where at least one tutee had a phone able to send and receive photos. Video clips were seen as "game changers" in how groups could interact and bond, although there were concerns that access to data-heavy videos could be a problem for students who had to pay for data.

4.8.5. Reflections from journal entries

The value of face-to-face contact between tutors and tutees was evident in the first tutee recruitment at a workshop for high school students on the university campus. A tutor-to-be explained why she felt the project would help the tutees and many tutees enthusiastically signed up. Two features seemed to "grab the attention" of the tutees: the tutor's background was similar to theirs and she was studying engineering, a prestigious degree with high entrance requirements. Having a near-peer explain how this project would support their academic goals appeared to be highly motivational for the tutees.

The value of face-to-face meetings was reinforced by tutors. Although the social media platform allowed for complete tutoring at a distance, there was a sense that tutees were reluctant to ask questions of a tutor they hardly knew. We reflected that there may be significant social discomfort for tutees, who are used to mixing languages and using slang on WhatsApp, when they try to communicate in English with a tutor who may not share their vocabulary and whose reaction was unpredictable, particularly when the communication would be witnessed by peers. A face-to-face meeting could alleviate concerns of negative reactions, develop trust among group members and develop a common understanding of what language could be used.

Through conversations with relatives of tutees, a research assistant learnt that parents were sometimes reluctant to let their children use WhatsApp when studying as they didn't believe that they were using it for work. It appeared that the consent form written in English was not very effective in explaining the project to parents. Alternative ways to explain the project were considered, including WhatsApp voice messages in parents' home languages, asking tutees to discuss the consent form with parents, and school visits during parents' meetings to talk to parents about the project and to demonstrate how to check WhatsApp conversations to ensure that their children are actually working on WhatsApp rather than just chatting. The need for more community engagement to ensure the success of the project became more apparent.

Concerns were raised about tutees sharing inappropriate comments or pictures, and potential chats to be used by tutors for relationship building. It was felt that recording all chats – and if necessary reminding participants that chats were recorded – would help to keep the chats mostly on tutoring topics and prevent offensive language and inappropriate pictures used on social media platforms where there is visual anonymity (Miller, 2014). There was a risk that recording chats may have inhibited some interaction, but this was necessary for our research aims.

4.9. Refined design principles for peer tutoring on social media platforms

The principles presented are based on literature on peer learning and social media use, and from surveys, interviews and reflections from participants in a WhatsApp mathematics tutoring project. The principles are grouped in three categories adapted from Topping and Ehly (2001):

- Communication and organisation
- Scaffolding, error management and cognitive conflict
- Emotional factors that influence learning

4.9.1. Design principles: Communication and organisation

- Use tutors with backgrounds similar to tutees to motivate tutees to join the tutoring project.
- Before tutoring starts, consent for recording chats must be given by participants, along with details on how to request the withdrawal of chats from research. Recording group chats may help to keep the focus on tutoring, keep communication polite and encourage members to participate in their roles.
- Parental/guardian consent can be encouraged with voice explanations in home languages and demonstrations of checking chat history to ensure that time on WhatsApp is spent on work.
- Face-to-face meetings can help to build trust relationships and encourage communication between tutors and tutees. Ideally, groups should be formed in a face-to-face meeting between tutors and tutees.
- When forming a group, participants should agree to terms of engagement, such as the languages that can be used, whether private questions to the tutor are allowed, times when an immediate response is more likely, if all participants can

reply to questions and whether sending videos, photos or voice messages is problematic in terms of device capacity and download costs.

- The use of familiar language including slang and emojis may help facilitate bonding between group members. Tutees who want to use specific languages should be with a tutor able to communicate in those languages. A signup form can facilitate matching like-language participants.
- Motivational messages and stimulating questions posted weekly can help to keep tutees engaged and on track.

4.9.2. Design principles: Scaffolding, error management and cognitive conflict

- A full solution from a tutor can model mathematical behaviour to tutees. However, tutors should first ask leading questions, give counter-examples or send a partial solution to help the student to resolve the problem.
- Tutors can ask for help from other tutors through a WhatsApp Tutors group or use sophisticated online calculators like symbolab.com and wolframalpha.com to check answers and maintain their 'more knowledgeable' status.
- Identifying errors is more likely when there are multiple participants compared to one-to-one tutoring. Tutors should encourage tutees to point out possible errors.
- Weekly questions sent by tutors can be chosen to produce cognitive conflict, such as questions on common misconceptions.

4.9.3. Design principles: Emotional factors that influence learning

- Face-to-face meetings can help develop tutor-tutee trust relationships and a sense of loyalty and accountability. A semi-structured script with questions to ask and a personal story to share could benefit shy tutors.
- Tutors and tutees may feel greater ownership of the project when they play multiple roles connected to their tutoring experience, e.g. tutees can help school peers who are not in a tutoring group and tutors can learn from other tutors.
- It is highly motivational for tutees to see themselves as being groomed to be future tutors. This expectation should be explained to them.

4.10. Further refinement of design principles

The principles above were refined over the first two years of the project based on input from tutors, tutees and researchers on what they felt led to more successful tutoring conditions. Focus group interviews with tutors in the third year of the project confirmed that these principles were mostly still relevant for the new students and tutors. Adjustments and additions to the principles were:

4.10.1. Additional design principles: Communication and organisation

- Donating WhatsApp bundles from cellular network providers to participants who do not have access to low-cost Wi-Fi can help to keep groups functioning.
- Tutees adapt to the language/s used by the tutors. It is not necessary to determine language preferences before setting up groups if all participants share the language of instruction of participants' school/university. Where tutees share a language, they can translate tutor explanations for other tutees.
- Students should be encouraged to send questions directly to the tutor. With the student's permission, a copy of a one-to-one chat about a question can be posted on the group for the benefit of other tutees.
- Tutees joining an established group should be sent the project information message privately rather than on the group chat.

4.10.2. Design principles: Scaffolding, error management, cognitive conflict

- The job of finding a weekly question to share can be rotated among tutors. The question can be posted on the tutors' WhatsApp group. Resources such as past papers can be shared among tutors on an online learning management system.

4.10.3. Design principles: Emotional factors that influence learning

- Volunteering to help others is a way to improve one's own well-being (Lyubomirsky, 2007/2016). This can be mentioned when recruiting new tutors.

4.11. Discussion and conclusion

The WhatsApp tutoring project has matured over the three years of its existence, underpinned by the evolving design principles, however challenges remain, suggesting further development of lines of inquiry. The challenges include operational issues related to the technology, group management of both people and time and, from a project management perspective, issues related to the student tutors.

Using mobile devices and WhatsApp is advantageous in certain ways (school learners are more likely to have access to a mobile device than a computer and WhatsApp is a ubiquitous app), but it also introduced challenges not present with other platforms. The greatest operational challenge was the unstable WhatsApp connection due to tutees' SIM cards moving in and out of devices shared with relatives, and a lack of data limiting WhatsApp activity. This problem will reduce as free Wi-Fi becomes available to tutees, as it is on the university campus to tutors. Providing tutees with monthly WhatsApp data bundles may help to keep tutees active. Ideally each tutee should have a personal device. Due to the difficulty of removing all personal data from a device, we were unable to find a source for donated devices (e.g. unclaimed devices confiscated for road offences). Future studies could investigate the barriers to using WhatsApp for tutoring, e.g. sharing phones with family members who only return home late, or a no-phone policy during family times.

Online tutoring saves travel time and cost, but occasional face-to-face meetings can improve the tutoring engagement by developing trust relationships between group members and may incentivise participants to remain actively involved. The available WhatsApp data bundles given to tutees excluded live calls via WhatsApp, which would be an alternative to face-to-face meetings if data costs and device functionality are not barriers.

The tutors experienced several group management issues, related to the group composition as well as balancing the challenges of timeous responses. Apart from losing tutees due to connectivity issues, group composition also changed as friends of tutees were added. Tutors felt that a group of 10 was still manageable. An alternative to splitting an active, large group is for a second tutor to join the group and share the responsibility of answering questions by, for example, responding on different days. Quick responses from tutors may help to keep tutees working on a problem. However, the time tutees spend on task may reduce if tutees rely on answers from tutors rather than thinking through the problem for themselves. Feedback that simply identifies and corrects an error may be minimally beneficial for tutor and tutee. Tutor guidelines should stress the negative effects of simply providing answers rather than questioning, prompting and breaking down problems (Topping, 1998). Participants may need training that provides examples of how to ask for, give and receive help. Exemplary chats can be shared with tutors and tutees, especially when groups are new. A lack of confidence in how to phrase questions may have contributed to the initial low participation in the tutees.

From a project management perspective, it is imperative that constant attention be paid to tutors' mathematical accuracy and a question remains on how to reward the student tutors for their work in a way which could benefit their CVs. We were concerned about ensuring that the tutors gave mathematically correct responses. Reviews of the recoded chats showed that tutors made few to no mathematical errors, possibly because they had access to peers and online calculators that can show steps, such as symbolab.com. Further research could investigate ways of ensuring quality control, such as anonymising and sharing chats for tutors or mathematics lecturers to rate. Volunteer tutoring hours can be included on tutors' resumés, but it is not clear how to estimate tutoring hours from WhatsApp chat histories, especially when they involve text, photos, videos and voice messages. Furthermore, emphasising the extrinsic gain to tutors may work against the intrinsic benefits of volunteering.

The principles presented above are context-specific to an environment without free internet access. While some of the challenges experienced will diminish as internet connectivity becomes more freely available, other principles would continue to apply. They provide guidance for others in similar settings who aim to use tutoring groups on a social media platform to achieve education goals.

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4.12. Reflection

Using design-based research, I developed and refined design principles for peer tutoring on social media platforms, as detailed in this chapter. Having established functioning WhatsApp tutoring groups, I planned to develop growth mindsets in the tutors using a teaching-on strategy, similar to mindset interventions used in many other studies. Short WhatsApp messages encouraging growth mindset behaviour were sent to tutors to share with tutees, and tutors were encouraged to share their personal experiences relating to the messages. However, tutors did not readily share the growth mindset messages or their experiences as expected. I started to explore possible reasons for the apparent uneasiness around sharing growth mindset messages: Were tutors unsure of an appropriate time to share these ideas? Did it feel inappropriate to send a message unrelated to the mathematics questions tutees were asking? How could the tutoring project be designed so that specific topics beyond mathematics would be included in the expected discourse? Perhaps a level of self-reflection was needed for tutors to notice their fixed mindset and growth mindset reactions and so be able to recall suitable experiences to share?

A second, and more pressing concern refocussed the direction of my research. Once the tutoring groups were operating effectively, the eight-item mindset survey showed that all the tutors already had growth mindsets, and many of them had strong mindsets. It was unexpected that *all* tutors should have growth mindsets. On average, the percentage of people with a fixed mindset is estimated to be about 40% (Dweck, Chiu & Hong, 1995). Most mindset studies only presented mean scores from mindset scales and not the number of students classified as holding fixed mindsets but a study of first-year computer science students reported that 21% held fixed mindsets (Cutts, Cutts, Draper, O'Donnell & Saffrey, 2010) and 15% of students in an introductory statistics course taken by undergraduate students in any year of study has fixed mindsets (Zonnefeld, 2015). I expected 15-20% of the larger group of first-year students (of which the tutors were a small subset) would have fixed mindsets and so the finding that there were less than half the anticipated number of students in the larger group with fixed mindsets caused me to explore more deeply how the mindsets of students change over their first year when they do not experience a targeted intervention to develop growth mindsets, and how growth mindsets are developed in first-year students at a South African university. These are the main topics covered in the next two chapters.

Chapter 5: Assessment of mindsets

5.1. Chapter introduction

Mindset assessment is important if you want to know whether or not mindsets are changing as a result of a mindset intervention. Quantitative and qualitative assessment of the mindsets of first-year students are described in this chapter. I agree with Fataar (2018) that student success can be improved by developing the affective dimension of students' transition into university, and I argue that developing growth mindsets is an important part of this transition.

Measurements of mindsets can also provide information on when to time interventions and for whom to design them. When students are challenged and start to question their ability, a fixed mindset can undermine academic behaviours, which can lead to poor performance and a reinforcing self-defeating cycle.

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5.2. Abstract

The affective dimension of students' transition into university is an area of development that has the potential to improve student success. Large-scale research suggests that developing a growth mindset belief – that academic ability can always be expanded – may be especially helpful for first generation students. A starting point for developing growth mindsets as one type of affective support for students is to investigate how we can position students on the fixed-to-growth spectrum of beliefs about academic ability. This mixed-methods study considers the changes during their first year of university in the mindset beliefs held by two representative first-year mathematics students, one who passed and one who had to repeat the second semester of mathematics. Without experiencing interventions aimed at developing growth mindsets, both students showed small shifts towards stronger growth mindsets over their first year. Limitations

with assessing mindsets are acknowledged and recommendations for future research in this area are suggested.

Keywords: First year experience, mathematics, mindsets, social-psychology, student success, transition.

5.3. Introduction

In South Africa, and particularly at the relatively well-resourced, research-focused university where I work, there is an ongoing drive to improve graduation rates and a recognition that student success is still racially skewed (Department of Higher Education and Training, 2019). Higher education is a key strategy to create social change through higher paying jobs (The World Bank Group, 2017). However, many students drop out of higher education, not only with broken dreams but often with debt.

Fataar (2018) provides insight into why the transition into university is especially difficult for first generation South African students. He describes how students use their pre-university paths, their activities at university, and their religious and cultural support to position themselves as learning agents who can achieve academic success. While this positioning can be helpful, first generation students often narrowly focus their university activity on achieving good results in tests and examinations (performance goals) rather than improving ability (mastery goals). Performance goals are in turn associated with believing that failure is due to a lack of ability (Ames & Archer, 1988; Dweck, 1986) and with self-handicapping academic behaviour, such as not asking questions and not completing homework (Niiya, Brook & Crocker, 2010).

Bangeni and Kapp (2005) claim that while universities focus on immersing students into academic discourses, teaching and learning activities neglect the affective dimension of students' transition. I go further and argue that an important aspect of the affective dimension of students' transition, particularly for first generation students, is developing the belief that academic ability is not fixed at birth but is always able to be expanded, a social-psychology theory based on the work of Dweck (2006). All students are likely to experience new academic struggles in their first year of university. These experiences may activate beliefs that lead students to question if they are the 'type' who can make it at university. If these beliefs are not challenged, perseverance decreases, academic behaviours are undermined, and the resulting poor performance reinforces the beliefs, forming a self-defeating cycle (Farrington et al., 2012).

5.3.1. Growth mindsets and fixed mindsets

Mindsets are self-beliefs that steer our behaviour by influencing motivation and self-regulation. A growth mindset, also called an incremental mindset, is the belief that our ability can always be developed (Dweck, 2006). At the other end of the spectrum, a fixed or entity mindset is the belief that our ability has a natural limit that we cannot do much to change. We may hold different mindsets about our ability in different fields (Scott & Ghinea, 2014); for example, we may hold a growth mindset belief that we can improve our mathematics ability with the right effort and enough time but also hold a fixed mindset belief that we could never master an unfamiliar language.

Over three decades of research have shown links between students' fixed or growth mindset beliefs and academic behaviour: fixed mindsets are associated with helplessness in the face of challenges (Dweck & Leggett, 1988), procrastination (Howell & Buro, 2009), and higher dropout rates from academic studies (Dai & Cromley, 2014; Heyman, Martyna & Bhatia, 2002), while students with growth mindsets show higher achievement in the transition to high school (Yeager & Dweck, 2012), care more about learning than marks (DeBacker et al., 2018), and show greater persistence when challenged (Boaler, 2015; Yeager, Walton & Cohen, 2013). A growth mindset encourages the behaviours that educators and employers wish for students to have, such as choosing to work on challenging rather than simple problems, collaborating, trying alternative methods when faced with failure. Fixed mindsets discourage effort, risk taking in new situations, exposing weaknesses, and reviewing errors to learn from mistakes.

Since academic behaviour directly impacts academic performance (Farrington et al., 2012), it is surprising that correlations between growth mindset and higher academic achievement (shown by, for example, Dweck & Molden, 2005; Eppler & Harju, 1997; Elliot & Dweck, 1988) are not found consistently (Burnett et al., 2013; Bazelais et al., 2018; Li & Bates, 2017; Sisk et al., 2018; West et al., 2016). Despite the shortcomings in the research results regarding mindsets, and the paradox of change being theoretically impossible for someone who holds a fixed mindset (Kristjánsson, 2008), the validity of the mindset theories has been defended (Dweck, 2017) and research in this area continues to grow (Zhu, Garcia & Alonzo, 2019).

Importantly, the impact of growth mindsets on academic achievement may be skewed in favour of students who are most at risk of dropout due to pressures from their low socio-economic status (SES). For example, a study of all grade 10 students at schools in Chile (Claro, Paunesku & Dweck, 2016) showed that while low SES predicted lower academic achievement than high SES, low SES students who held growth mindsets achieved at the same level as high SES students. Furthermore, low SES students and low-achieving students in this nationwide study were more likely to hold fixed mindsets, and, compared to SES, mindset was a stronger predictor of academic achievement. The greater benefit of growth mindsets on achievement by low SES students and minority groups was confirmed in two meta-analyses by Sisk et al. (2018), although the effect of growth mindsets on achievement was overall small. This research suggests that fixed mindsets may be a factor perpetuating the achievement gap between low and high SES students.

Similarly, Kapp et al. (2014) found that religious and cultural support enabled South African students from low SES backgrounds to position themselves as learning agents. However, family, friends, or religious beliefs may reinforce fixed mindsets and performance goals, for example, “Your intelligence is a gift from God”, “You are an A-student”. Parents’ fixed mindset reactions to failure have been shown to induce fixed mindsets in their children (Haimovitz & Dweck, 2017). Therefore, turning to their usual support systems when failing a test for the first time may push students towards fixed mindset beliefs. These beliefs discourage students from seeking help as they try harder to maintain an image of being a strong student who does not need support. In contrast, “What can you learn from your mistakes? Where can you get help?” is an example of growth mindset support that may encourage self-reflection and the use of feedback for self-development.

5.3.2. Aim

A starting point for developing growth mindsets as one type of affective support for first generation students is to investigate where students position themselves on the fixed-to-growth spectrum of beliefs about academic ability. In this paper, I consider the mindset beliefs held by two representative first-year mathematics students and how their beliefs do or do not change during their first year of university. If we find that students do not have strong growth mindsets, this would indicate that it would be worth doing further research on (1) how to develop growth mindsets, including through affective support such as the words and actions of lecturers, friends, family and support communities, and (2) how mindsets affect academic success.

5.3.3. Research question

The research question is: *How do students' beliefs about academic ability in university mathematics shift in their first year of university?*

5.4. Methods and methodology

The focus of this research was an in-depth exploration of the mindsets of first year students through interviews. Contextualisation of the interviewed students' mindsets in relation to their peers was provided by surveying first year mathematics students using an existing eight-item questionnaire freely available at http://blog.mindsetworks.com/what-is-my-mindset (Mindset Works, 2015). Four items aligned to growth mindsets (e.g. "No matter how much intelligence you have, you can always change it a good deal") and four aligned to fixed mindsets (e.g. "You can learn new things, but you cannot really change your basic level of intelligence"). Response choices were on a six-point scale from 'disagree a lot' = 1 to 'agree a lot' = 6 for growth mindset items. The fixed mindset items were reverse-scored, so that high scores represent a growth mindset. Following Dweck, Chiu and Hong (1995), weighted scores of 25 to 31 were classified as representing neither fixed nor growth mindsets. The five-section grouping of weighted scores shown in Table 5.1 was adapted from the Mindset Assessment Profile Tool (2012).

Table 5.1: Classification of mindset according to weighted score from mindset questionnaire

Weighted mindset score	8 to 16	17 to 24	25 to 31	32 to 39	40 to 48
Classification	Strong fixed mindset	Moderate fixed mindset	Neutral mindset	Moderate growth mindset	Strong growth mindset

The questionnaire was piloted using a sample of 49 students in a first year mathematics course at a South African university in 2017. As all eight items in the questionnaire were designed to measure mindset, the Cronbach alpha coefficient was a suitable measure of reliability (that is, the extent to which the questionnaire can be expected to return the same results when reused) and internal consistency (if the items are all measuring mindset). A Cronbach alpha coefficient value of 0.71 suggested that the questionnaire could be expected to give the same outcomes for the target population of students at a South African university.

After obtaining ethical clearance from the university where the study took place, first year mathematics students were asked to complete the questionnaire on an online learning platform used for regular homework tasks, in the first term of the 2018 academic year. Students voluntarily participated and were incentivised with a bonus homework point if they completed the questionnaire. They were assured of their anonymity in research publications. A total of 265 students submitted responses to the questionnaire in the first term. The analysis of responses on Excel was used to ensure that the selection of interviewed students for in-depth analysis were representative. Due to a low response rate of only 27 students in the end-of-year questionnaire, comparisons between the questionnaires were not made.

Interviews of up to thirty minutes were held with students who had completed the questionnaire and who volunteered to be interviewed. These interviews took place in the first year, within the first month of university (n = 16) and in the second semester (n = 15). The interviewer was not involved in the teaching or assessment of the course. No incentives were offered for participation in the interviews.

Interviews were recorded and analysed by identifying responses that matched characteristics of fixed and growth mindsets described in Dweck (2006), namely how students dealt with challenges, feedback, criticism and the success of others; how they viewed effort, mistakes, and marks. After a comparison of interview data, two representative students were selected to describe in detail.

5.5. Results and discussion

The questionnaire results completed in the first term of 2018 by mathematics students at a South African university are summarised in Table 5.2. For the 248 students who provided consent for their results to be used for research, a Cronbach alpha coefficient was calculated as 0.62, below the recommended minimum value of 0.7 but within the range of 0.6 - 0.7 that is commonly, but not contentiously, referred to as acceptable (Taber, 2018).

Table 5.2: Classification of mindset according to weighted score from mindset questionnaire

Weighted mindset score	8 to 16	17 to 24	25 to 31	32 to 39	40 to 48
Classification	Strong fixed mindset	Moderate fixed mindset	Neutral mindset	Moderate growth mindset	Strong growth mindset
Number of students (Total: 248)	2	15	64	139	28
Percentage	1%	6%	26%	56%	11%

Using to the classification from Table 5.1, only 7% of students identified as having fixed mindsets, 26% had indeterminate or 'neutral' mindsets and 67% of the 248 students had growth mindsets.

In interviews, there were no students who consistently gave responses that matched only-growth or only-fixed mindsets. Assessments of students' mindsets were guided by the breakdown of mindset characteristics as fixed, low growth, mixed, growth and high growth according to The Mindset Continuum (Anderson, 2019b). Questionnaire and interview data were analysed in conjunction to make mindset assessments.

I will focus on the academic mindsets of two students I will call Pearl and Khalil. At the start of the year, Pearl's responses to the eight-item mindset questionnaire indicated a moderate growth mindset, with a weighted score of 34 on the scale from 8 (strong fixed mindset) to 48 (strong growth mindset). Khalil's responses at the start of his first year showed an overall neutral mindset, with a weighted score of 29. The items in the questionnaire, together with responses from Pearl and Khalil and the interpretations of their responses are presented in Table 5.3.

Table 5.3: Interpretation of two students' responses to Mindset Assessment Profile Tool (2012) items from strong fixed mindset (1) to strong growth mindset (6)

Items in eight-item mindset questionnaire	Pearl's responses	Interpretation	Khalil's responses	Interpretation
No matter how much intelligence you have, you can always change it a good deal.	Agree (5)	Growth	Agree (5)	Growth

You can learn new things, but you cannot really change your basic level of intelligence.	Disagree a lot (6)	Strong growth	Disagree a little (4)	Weak growth
I like my work best when it makes me think hard.	Agree a little (4)	Weak growth	Agree a little (4)	Weak growth
I like my work best when I can do it really well without too much trouble.	Agree a lot (1)	Strong fixed	Agree a little (3)	Weak fixed
I like work that I'll learn from even if I make a lot of mistakes.	Agree a lot (6)	Strong growth	Agree a lot (6)	Strong growth
I like my work best when I can do it perfectly without any mistakes.	Agree a little (3)	Weak fixed	Agree a lot (1)	Strong fixed
When something is hard, it just makes me want to work more on it, not less.	Agree (5)	Growth	Disagree a lot (1)	Strong fixed
To tell the truth, when I work hard, it makes me feel as though I'm not very smart.	Disagree a little (4)	Weak growth	Disagree (5)	Growth
Mindset Classification from Table 5.1	**Score: 34**	**Moderate growth mindset**	**Score: 29**	**Neutral mindset**

The value that Pearl placed on learning from mistakes is consistent, evident in her questionnaire responses and both interviews. When asked if she believed that people are born as 'maths people,' she strongly disagreed:

> No, no, no, I don't think so. 'Cos I didn't like maths for a very long time in my life. ... It doesn't matter whether you like it or not. It makes it easier if your heart is there, but if you put your mind to something I feel that you can do it, it doesn't matter if you're a maths person or you were born with it, I don't believe that. ... I feel like if you just put your mind to something, to make it work, it does work.

At the end of the year, when asked about behaviour that might lead to not being successful in mathematics, Pearl spoke about a friend who had placed great pressure on herself to achieve high marks (grades):

> Sometimes people pressure themselves too much. I have a friend, ... actually she likes maths, and she does maths all the time and she wants to get like those h-i-g-h marks, so then now she puts pressure so much on herself that I feel like it's also affecting her marks ... and it's affecting her mentally as well.

From her first to second interview, Pearl shifted from a desire to achieve a high mark to achieving a pass without worrying about what mark she obtained:

> ... you can do work and work hard but not pressurise yourself to a point where, 'I need to get a certain mark, I need to get 90.' ... So, I'm just working on my progress right now. If I get 90, I'll be happy but if it happens, it happens, I'm not going to pressure myself, as long as I'm passing that's what matters to me.

Pearl's de-emphasis on achieving high marks indicates a move away from performance goals, associated with fixed mindsets, towards mastery goals, which are associated with growth mindsets (Eppler & Harju, 1997). Pearl suggested that her friend's focus on marks may have come from a desire to be recognised in class as a top achiever:

> I feel like, people in our class, people are smart (laughs), I won't lie, people are smart, some people just get 100% and .... usually last semester our lecturer would say people are getting 100% and he'd congratulate them, which is a good thing, and now I feel like people pressurise themselves into getting those good marks maybe to be recognised as well, or, I don't know.

Growth mindset characteristics that Pearl displayed in the second interview are the beliefs that you do not need to be quick to be able to achieve in mathematics, and that mistakes give valuable opportunities to learn:

> That's how I think I learnt at school. I'd write homework and then I'd get them wrong, coming to corrections I'd get probably 90% of my homework wrong... and then, like, there are silly mistakes, 'cos I'm like, it takes me a long time to understand something... So it takes, like, I won't get everything right but I'll get 90% of the questions wrong but then I go back, I look at the answers, or the teacher explains again, like step by step what happens, so then I'm able to rectify, 'Ok, this is what happens.'

Fixed mindsets encourage students to hide their difficulties to prevent being judged as weak. Pearl displayed a growth mindset by making use of mentors throughout the year. At the end of the year, she identified time management as an area of weakness for her and explained how she was getting help with this:

> I still feel like time management, hey, *time management*! is bad. Um, but I'm working with my mentor, my physics one and my maths one and they're helping a lot. I'm

> going to stick with them again ‘cos I feel like having them in my life ... makes a huge difference, so I’ll keep on going to MLC [Mathematics Learning Centre][1] ... and organise my time.

Like Pearl, Khalil showed a shift towards a stronger growth mindset in the context of mathematics over his first year. At the start of the year, Khalil disagreed strongly with the statement ‘When something is hard, it just makes me want to work more on it, not less,’ – a strong fixed mindset response. At the end of the year, he seemed to hold contradictory views regarding challenges, both enjoying a challenge and trying alternative methods (growth mindset traits) but also feeling frustration when challenged, which is more of a fixed mindset characteristic:

> If you can see where you have to go, like, even if it’s difficult, the process that has to happen, it’s like okay, cool, so this is an integration problem, for example, then the challenge will be to integrate but like as long as we can see where we have to go. It’s frustrating not knowing what to do. I’ll try a few methods.

While Khalil started the year strongly agreeing that he preferred working without any mistakes, he shifted towards being more comfortable with making mistakes, although this seems to be in the context of being able to resolve the mistakes easily.

> Generally, I just fly through everything. If I make a mistake I’ll be like ‘Cool, how do you fix it? I fixed it. Great.’

However, at the end of the year, Khalil was more endorsing of the fixed mindset idea that working hard may go together with not being very smart, as seen in his procrastination tactics (shown by Howell & Buro (2009) to predict fixed mindsets) and labelling himself as lazy.

> I feel like I’m personally the laziest student in the world that you will find in your life. With the degree that we’re doing [engineering] you can’t be lazy so, [I do] the bare minimum, but you still have to put in the effort. I guess it’s more like how long can you leave it until you start putting in the effort, and if it is an effort then you go through the process of figuring out what to do and afterwards its easy or you decide to leave it and focus on the rest of the coursework.

[1] The Mathematics Learning Centre, or Maths Hotseat is a space where students can work individually or in groups during free times. Tutors assist students with specific questions from lectures or tutorials.

At the end of the year, Khalil still identified himself as a procrastinator, but his reasons appear to be linked to rejecting performance goals.

> I'm not one to study on Monday for a tut test on Friday. It also becomes a thing of what's more important, learning or marks? It's like 'I know these two questions are going to come up in the test, let's just learn these two questions,' and then nothing is really learnt.

Khalil's rejection of performance or even strategic learning goals (Biggs, 1979) match the strengthening of his growth mindset. However, by the end of his first year, Khalil does not yet appear to have developed the necessary work habits that will support mastery goals. When asked why some students have high achievement in university learning, he identifies helpful behaviours – diligence and consistency – but seems to view diligence as a fixed trait rather than something he could develop.

> I think it's maybe just diligence. Because that's the one thing that I would … if I could be a diligent student then I think I would do a lot better than I'm doing right now.
>
> *Interviewer*: And what would that entail?
>
> Being consistent. 'We're going to class, we're coming home, we're doing this.' As opposed to 'Ok, maybe tomorrow we'll do all the things we need to.'

While a fixed mindset may prevent a student from even trying to achieve an academic challenge, having a growth mindset is not enough for academic success. Academic improvement does not happen unless students actually engage in effective practices. This was confirmed in the case of Khalil. His openness to learning from mistakes, rejection of performance goals, and comfort with challenges are growth mindset characteristics, however recognising that his work habits did not include enough diligence or consistency did not translate to effective action and he had to repeat the second semester mathematics course.

5.6. Limitations and directions for future research

A focus on mindsets may lead a researcher to fall into the trap of 'fundamental error attribution' - giving attention to attitudes and personality but overlooking 'how profoundly the social environment affects what we do and who we are' (Kohn, 2015: p.3). Pairing growth mindset development with effective strategies to manage issues such as procrastination, as suggested by Job, Walton, Bernecker and Dweck (2015), may result in better academic achievement. Further research linking growth mindset development with effective learning habits, as suggested by Yan, Thai and Bjork (2014) and Anderson (2017) but aimed at higher education is suggested.

The effect of mindset on achievement may be eclipsed by the larger impact of institutional and course features, including lecturers' assumptions of students' prerequisite knowledge (Solina, 2019) and a focus on competitive achievement of marks rather than learning (Kohn, 2015). Future research could look at how course design features – assessment practices, reward systems, lecturers' speech and actions – can promote growth mindsets in lecturers and students, and what impact this could have on student success. I suggest that setting assessment at the right level and developing students' understanding of what they are expected to do, and how to achieve it if they are underperforming, supersedes the effects of mindset orientations.

The low percentage (7%) of students identified with fixed mindsets according to the questionnaire used in this study may be an indication that the questionnaire is not being interpreted as intended by students in a South African university. Validation of the questionnaire, or alternative versions with personalised and domain specific items (De Castella & Byrne, 2015; Nelson, Gee & Hoegler, 2016; Pembridge & Rodgers, 2018) would increase confidence that the questionnaire results are reliably measuring mindsets.

Fixed mindsets can be triggered by ego-threatening situations (e.g. failing a test, Burnette et al., 2013). The nuances of situation-dependent changes to mindset and the timing of these in relation to study time, test time and times when students took the mindset survey or were interviewed, may skew our understanding of what is actually the connection between students' beliefs, actions and behaviours. Gilbert (2007) points out how our recollection of past experiences is strongly influenced by our present circumstances. So, if a student is interviewed soon after performing well in a quiz, they may forget how difficult it may have been when they were struggling.

The impact of not addressing the affective needs of students through promoting growth mindset beliefs is likely to have a greater impact on students from low socio-economic backgrounds. A study involving 150 000 students and 150 lecturers from STEM courses (Canning, Muenks, Green & Murphy, 2019) found that, compared to classes with growth mindset lecturers, students in classes with fixed mindset lecturers had lower motivation and the racial achievement gaps were double. Raising awareness in lecturers, students' supporters, and universities broadly of the damaging impact from fixed mindset beliefs is strongly recommended as an area for further research and action.

5.7. Conclusion

Bangeni and Kapp (2005) suggested that a lack of affective support from teaching and learning activities at universities may contribute to student under-achievement. Since students with fixed mindsets are most at risk of dropout from university studies (Dai & Cromley, 2014; Heyman at al., 2002), developing growth mindsets is one form of affective support that can benefit students with a history of high achievement at school but who experience academic struggles in their first year at university. While the link between growth mindsets and grades has not been established for mathematics students at a South African university, the characteristics of a student holding a growth mindset match with desirable graduate outcomes, such as persistence in the face of difficult challenges, being willing to put in effort to achieve goals, seeking and accepting help when necessary.

This research provides two examples of how students' beliefs about ability in university mathematics shift in their first year, without any targeted intervention to develop growth mindsets. Pearl began her first year as a student with a moderate growth mindset. She believed that her efforts would lead to success in mathematics, but she also focussed on achieving high marks as a measure of her ability – a trait that Fataar (2018) noted is typical of many South African students. Towards the end of her first year, Pearl had developed practices that indicated a shift to a stronger growth mindset, such as asking for help and putting in effort to achieve learning. She saw that focussing on achieving high marks harmed a friend's test performance and mental well-being, and she had dropped the goal of achieving high marks in favour of mastery goals. At the end of her first year, Pearl considered herself as a learner who needs more time to fully understand problems but was confident that she could succeed by working hard and seeking help when stuck, which indicate a strong growth mindset.

Khalil's statements at the end of the year that he can 'fly through everything,' but that he is inherently lazy and not 'a diligent student' indicate fixed mindset beliefs. Yet he also displayed antipathy towards chasing marks rather than learning and rejected performance goals, which is characteristic of a growth mindset (Eppler & Harju, 1997).

A growth mindset defends against overconfidence by making students more open to try more difficult problems, thereby developing a more accurate assessment of current ability (Ehrlinger, Mitchum & Dweck, 2016). While Khalil passed the first semester mathematics course, he had to repeat the more challenging second semester course. With the habit of working fast, it is possible that Khalil avoided struggling on problems, and that this avoidance was due to fixed mindset beliefs.

This in-depth study showed that mathematics students at a South African university held fixed mindsets alongside growth mindsets, and that even without a targeted intervention, mindsets shifted slightly towards growth mindsets over their first year. Future research on the role that universities and communities could play in supporting growth mindsets development in first year students is highly recommended and may help students to avoid self-defeating cycles and to realise the academic success hoped for by all stakeholders.

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5.8. Reflection

Assessing mindsets is complex, partly because mindset beliefs are not dichotomous – we can hold both fixed and growth mindset beliefs simultaneously, for example, we may believe that effort will improve our ability to write an essay, but that natural talent limits our ability to improve in problem solving. Mindset scales imply that fixed and growth mindsets are either-or beliefs, but interviews show how an individual's mindset beliefs are interwoven combinations of both. Mindset assessment is further complicated by the variety of original and modified mindset scales and the number of Likert scale options used across studies, as described in the literature review in chapter three. Current circumstances may pull some beliefs to the foreground and cause other beliefs to recede. Hence, as suggested in the theoretical framework in chapter two, educators need to be aware of how they may be promoting fixed or growth mindset beliefs. The role of the environment in shaping mindsets will be further discussed in chapter six.

In this chapter I investigated how students' beliefs about academic ability in university mathematics shift in their first year of university by analysing survey responses by 265 first-year engineering students and interviews with 16 students. The in-depth analysis of mindsets for two students showed a small shift towards stronger growth mindsets over their first year at university, a finding that provides a baseline measure for this population of students at a South African university and contributes to global understanding of the mindsets of first-year university students.

The concluding chapter of the thesis focuses on answering the central research question of the thesis, *How can growth mindsets be developed in engineering students?*

Chapter 6: Mindset interventions must target learning environments, not just students

6.1. Chapter introduction

In the previous chapter I established that there was a low occurrence of fixed mindsets among the 265 surveyed first-year engineering students at a South African university. This surprising finding led me to focus on *how* students developed growth mindset characteristics.

In this chapter, I answer the final three of the secondary research questions:

- *How can social psychology theories explain why it is difficult to implement mindset interventions and to get an accurate assessment of mindset?*
- *What can be identified from growth mindset literature as experiences that promote the development of growth mindsets?*
- *Which experiences that develop growth mindsets do first-year students recall from their school and first-year experience?*

To answer the first research question, I reviewed social psychology research to find reasons why mindset interventions may fail to reach their goals. The major finding was that mindsets can be distinguished as *deliberate*, meaning they can be induced, or *dispositional*, meaning they reflect beliefs about your fundamental capabilities (Heslin, Keating & Ashford, 2019). Interventions that target deliberate growth mindsets may have short-lived effects. To have long-lasting results, mindset interventions need to target dispositional mindsets. Another important finding was that mindset interventions may appear to be less effective than theoretically expected because participants are at different stages of behaviour change. Social psychology literature also provides explanations for why growth mindset assessments could give misleading results. The findings will help to strengthen the trustworthiness of students' responses to mindset questionnaires and improve the quality of research involving mindset assessment.

To answer the second research question, *What can be identified from growth mindset literature as experiences that promote the development of growth mindsets?* I presented a summary of examples that show how learning environments can support the development of growth mindsets.

To address the final research question, *Which experiences that develop growth mindsets do first-year students recall from their school and first-year experience?* I identified ten growth mindset enabling experiences from literature and compared them with interview responses from seven first-year engineering students. Six of the ten identified experiences were found to be common to all interviewed students. The literature-sourced experiences that did not match the students' experiences contribute to the understanding of how growth mindsets develop in South African students.

The thesis is concluded with a final reflection that draws together the findings of this chapter and the earlier chapters in regard to the central research question of the thesis, *How can growth mindsets be developed in engineering students?* Limitations and suggestions for further research are presented.

This chapter has been written as a journal article which is currently under review:

Campbell, A. L. (submitted for review). Enabling growth mindsets: Shifting the focus from students to learning environments.

---------------------------- Start of journal article ----------------------------

6.2. Abstract

The value of growth mindsets for student success has been shown in many contexts. As a result, many growth mindset interventions have been developed, but these have limited value when participants are assessed as already having growth mindsets. To find out how growth mindsets may develop, a comparison is made between literature-sourced experiences that enable growth mindsets and interview data from seven first-year engineering students at a South African university. Drawing on social psychology research, limitations with mindset interventions and mindset assessment are presented. Suggestions are made for creating learning spaces that support growth mindset development. Using the dual-model of mindsets as *dispositional* (reflecting beliefs about who you fundamentally are and what you are or are not capable of), or *deliberate* (able to be invoked), it is argued that growth mindset interventions need to focus on developing mindsets in learning environments and not just in individuals.

Keywords: Academic achievement; engineering students; growth mindset; implicit theories of intelligence; student success.

6.3. Introduction

Sam, a top achiever in high school, has failed a first semester university mathematics test. In a meeting with the mathematics lecturer, Sam lists the behaviour changes that would make success more likely, such as asking questions when stuck, completing all assigned homework, collecting and reviewing marked tests. Yet Sam fails to implement these actions and fails again.

Sam's behaviour is symptomatic of what Dweck (2006) termed a fixed mindset – the belief that ability is inherent and cannot be changed beyond a basic level. The opposite belief, a growth mindset, would free Sam from wanting to hide from areas of weakness. The growth mindset belief that ability can change as a result of appropriate effort shifts the goal from *proving* ability to *developing* ability.

Growth mindsets can increase student success by enabling students to make better use of learning opportunities (Yeager & Walton, 2011). Robins and Pals (2002) found that, compared to growth mindset students, college students with fixed mindsets were more likely to show psychological weakness in assessment situations and to attribute their academic performance to factors beyond their control. On the other hand, since growth mindset students believe that working hard leads to mastery, they are more likely to have an internal locus of control, which is associated with higher academic achievement (Findley & Cooper, 1983).

Developing growth mindsets is significant for many reasons. Academically, a nationwide study in Chile showed that grade 10 students with growth mindsets had higher language and mathematics achievement than grade 10 students with fixed mindsets, and that the lower achievement typical of low income students was offset by growth mindset beliefs (Claro, Paunesku & Dweck, 2016). Growth mindset college students in America were more likely than fixed mindset students to be intrinsically motivated to learn and to value beneficial practices such as self-testing and restudying (Yan, Thai & Bjork, 2014). Emotionally, fixed mindsets in Filipino secondary school students predicted negative emotions such as anger, anxiety, shame, hopelessness, and boredom (King, McInerney & Watkins, 2012), youth in America with fixed mindsets experienced more academic distress and more mental health difficulties than youth with growth mindsets (Schleider, Abel & Weisz, 2015), and university students in Mexico with growth (versus fixed) mindsets had greater well-being (Ortiz Alvarado, Rodríguez Ontiveros & Ayala Gaytán, 2019). Politically, studies in India and the United States of America showed that growth mindsets predicted increased support for policies aimed at redressing social inequality (Rattan, Savani, Naidu & Dweck, 2012). A meta-analytic review by Costa and Faria (2018) concluded that in stressful or demanding situations, students with growth mindsets are more likely than students with fixed mindsets to adapt and succeed.

Given the advantages of growth mindsets over fixed mindsets, many interventions to develop growth mindsets have been devised and tested (Sarrasin et al., 2018; Campbell, Direito & Mokhithi, 2019). Many of the existing interventions to develop growth mindsets in communities focus on developing growth mindsets in school-aged children and their teachers and caregivers, where the long-term impact of the intervention can be highest, and include online courses and resources (Anderson, 2019a; Boaler et al., 2018; PERTS Mindset Kit, 2020; The Learner Lab, 2020; youcubed.com). However, while many interventions involving child or adult participants succeeded in developing growth mindsets, results have not been consistently reproduced (Sisk et al., 2018).

The central purpose of this study is to explore how growth mindsets can be developed in university students. Three sub-goals are set to achieve this purpose:

- Show how social psychology theories can explain why it is difficult to implement mindset interventions and to get an accurate assessment of mindset;
- Summarise examples of how learning environments can support the development of growth mindsets; and
- Compare literature-sourced experiences that promote the development of growth mindsets with interview data from engineering students in which they recall the experiences occurring (or not) in their past.

The research question answered by empirical interview data is, *What experiences that develop growth mindsets do first-year engineering students recall?*

6.4. Social psychology insights on why mindset interventions might fail

Social psychologists study how people's interpretations of situations influence their thoughts, feelings and behaviours (Ross & Nisbett, 1991/2011). In the following two sections, social psychology literature provides insights on problems with implementing growth mindset interventions and with assessing mindsets.

6.4.1. Limitations of mindset interventions

This section describes how environmental factors can lead to unsuitable or unsustained interventions, how intervention design can be improved using theories on attitude change and persuasion, and how the dual-model of mindsets and the five-stage theory of behaviour change can explain why some growth mindset interventions have short-lived effects.

Environmental factors

To be effective, interventions must be implemented in a ways that suit the context of the educational environment (Yeager & Walton, 2011; Robinson, 2019). Intervention design should consider the strong effect that other people have on shaping our beliefs and behaviours (Briceño, 2015), including how adults' behaviours are shaped by what they observe in children (Haimovitz & Dweck, 2017). Heslin, Keating and Minbashian (2019: 2112) theorise how environmental cues and mindsets work with personality traits to influence the outcome of experiences:

> "Prevailing mindsets vary from occasion to occasion—based on the mindset cues to which individuals are exposed—and shape the thoughts, feelings, and behaviors that they exhibit in that instance."

Regarding the effects of mindset interventions on academic achievement, a crucial point is that removing barriers to learning or increasing motivation to learn is insufficient – the environment must also provide learning opportunities for students (Yeager & Walton, 2011). Intervention design should consider the strong effect that other people have on shaping our beliefs and behaviours (Briceño, 2015), including how adults' behaviours are shaped by what they observe in children (Haimovitz & Dweck, 2017). To sustain the effects of an initial mindset intervention, Leung (2018) recommends that mindset interventions should connect with existing recursive processes in the environment, and Orosz, Péter-Szarka, Bőthe, Tóth-Király and Berger (2017) recommend a follow-up after an initial intervention. Importantly, researchers should defend against falling into a 'fundamental error attribution' trap by giving attention to attitudes and personality but overlooking 'how profoundly the social environment affects what we do and who we are' (Kohn, 2015: p.3).

Walton and Cohen (2011) raise two potential limitations for social psychological interventions: the context must give opportunities for participants to learn, and an openly hostile environment may derail interventions that aim to change how participants interpret ambiguous events, such as feeling excluded. The important implication is that interventions directed at students, such as an online reading and writing activity that students can do alone (Broda et al., 2018), need to consider the broader social space in which students operate.

Attitude change and persuasion

Bettinger, Ludvigsen, Rege, Solli and Yeager (2018) explain how social psychology theories about attitude change and persuasion can help to counteract the problem of short-lived effects from mindset interventions. For example, the design of a brief, two-session, online mindset intervention included persuasive features to portray the growth mindset message as *memorable*, *credible*, *normal*, and *important* in the following ways. Repetition of the metaphor of the brain as a muscle in both sessions made the theory more memorable. Using quotations from scientists and celebrities endorsing brain growth theory and the benefits of a stronger brain added credibility, and quotations from past participants endorsing mindset theory made acceptance of the theory seem socially normal. Discussing the benefits to society from oneself adopting and using growth mindsets added importance.

Dispositional and deliberate beliefs

Heslin et al.'s (2019) dual-process model of mindsets as *dispositional* (reflecting beliefs about who you fundamentally are and what you are or are not capable of), or *deliberate* (able to be invoked) provides a framework for understanding the "nuances and complications that confront the educator" when using social psychological interventions (Spitzer & Aronson, 2015: 12). For example, interventions that invoke a growth mindset response to disappointments or that prime a student to respond to a challenge with a learning-mode response (Heslin & Keating, 2017) could be said to target a deliberate growth mindset. If the intervention aims to shift dispositional mindsets, more action may be required, for example reinforcing the intervention through repeated messages from influential people such as teachers, professors or parents (Willeke, 2015).

The five-stage model of behaviour change

A widely-cited five-stage model of behaviour change (Prochaska & DiClemente, 1983; Moore, 2005) proposes that lasting change requires movement through stages of pre-contemplation, contemplation, preparation, action and maintenance. The five-stage model helps to explain the link between self-beliefs, behaviour change and student success in education settings. Mindset interventions aim to develop behaviour that increases student success by changing the self-beliefs that individuals hold. Since fixed mindsets can block a person from taking actions that lead to success (such as asking for help), growth mindset interventions can help to move a person through the first three stages of behaviour change: an awareness of mindset theory can put a person into pre-contemplation; recognising the benefits of a growth mindset and the negative consequences of a fixed mindset can move a person to contemplation; and participating in a mindset intervention indicates preparation for behaviour change. The last two stages of action and maintenance represent the behaviour change processes that are the intended outcomes of mindset interventions in educational settings.

The five-stage model explains how once-off or short-term mindset interventions may appear to be less effective than theoretically expected. A limitation of applying the five-stage model of behaviour change to mindset interventions is that the model lacks a feedback cycle that allows further contemplation, preparation and action as a result of initial action.

6.4.2. Factors that shape mindset assessment results

Separate from questions regarding the statistical reliability of quantitative mindset assessment tools, which are discussed at length elsewhere (Hong et al., 1999; Ingebrigtsen, 2018) there are other reasons why growth mindset assessment may give misleading results. Two groupings of reasons are considered in this section: issues around assessing beliefs and issues around the use of a Likert-style scale for assessing mindsets.

Issues around assessing beliefs

Two difficulties in assessing growth mindset interventions can be explained using the five-stage model of behaviour change (Prochaska & DiClemente, 1983). Firstly, participants may be at different stages of change from each other. An intervention may, for example, move some participants to the stage of pre-contemplation but others to the stage of action due to prior exposure to mindset theory. Secondly, the preparation stage is usually marked by a plan to make a change within the next month, and the contemplation stage by a plan to change within the next six months. A mindset intervention lasting less than half a year may shift behaviour to the stage of action or maintenance, but changes in academic achievement as a result of the behaviour change may lag beyond the data collection time, especially if within the same semester or year.

The timing of mindset assessment may distort the results. Gilbert (2007) shows that present circumstances dominate our attention, and Cutts et al. (2010) suggest that fixed mindsets responses can be induced by failure. Therefore, if students feel confident when they completed a mindset survey, such as in the first weeks of university, before taking tests, they are more likely to be assessed as having a growth mindset. After failing a test, students with fixed mindset beliefs are less likely to volunteer to take a survey or to be interviewed, as they may want to hide their academic shortcomings. Studies where the percentage participation from a population is not close to 100% may disproportionally exclude low-performing students with fixed mindsets. A level of psychological safety (Edmondson & Lei, 2014) and trust in the researchers may be necessary for students to feel confident to participate in research and to answer honestly when they do.

However, even when students freely participate in research, their honest answers may not match their underlying beliefs. Mercer and Ryan (2009) describe two 'scripts' of declarations that may not match behaviour. The first is declaring that natural talent matters most (and so being assessed as having a fixed mindset) but behaving as if hard work is necessary to enhance ability. The second is declaring that effort leads to success (a growth mindset) but not working hard or persisting when challenged, suggesting a belief in effortless talent. Students may use these scripts unconsciously, perhaps developing them in response to what they think teachers or others believe or value.

Issues around the use of mindset scales

While Dweck (2016) has been clear that everyone has a combination of both types of mindsets, it has been argued that the structure of the mindset assessment scales aims to force a choice between fixed and growth mindset (Kristjánsson, 2008) rather than recognizing that everyone has a mix of growth mindsets and fixed mindsets. It is possible that responses to surveys using a mindset scale may classify people with stronger fixed or growth mindsets than would be determined using interview responses or a different mindset scale.

For college students, a domain-specific variation of Dweck's (2000) mindset scale was found to be as reliable as the original scale, however, growth mindset beliefs about domain-specific intelligence were stronger than general beliefs about intelligence (Nelson et al., 2016). This suggests that the strong growth mindset assessments from the domain-specific mindset scale used in the present study may be inflated. Since the mindset assessment scores for the seven interviewed students indicated strong growth mindsets, it is likely that the original mindset scale would also assess the students as having growth mindsets.

Safrudiannur and Rott (2019) have criticised the use of Likert scale instruments for measuring beliefs. Compared with interviews and observations, responses on Likert scale instruments tended to be biased towards beliefs seen as socially desirable.

Finally, a key limitation in testing the efficacy of interventions occurs when the number of students identified through surveys and interviews as already having growth mindsets is high (Frary, 2018; Campbell, 2019). Regardless of whether the assessments are a true or distorted representation of the students' mindsets, changes towards growth mindsets are less possible when results are already clustered at the growth mindset end of the mindset scale spectrum.

6.4.3. How learning environments can support the development of growth mindsets

Examples from literature of how learning environments can support the development of growth mindsets are shown in Table 6.1, grouped in the categories:

- Perceptions of learning
- Tasks and assessments

- Community norms

Table 6.1 Examples from literature on how learning environments can support the development of growth mindsets

Perceptions of learning
• Explicitly state in course objectives that the goal of learning activities is to facilitate learning and development (Boucher & Murphy, 2017). • Strongly emphasise 'learning-to-learn' goals in which students to measure themselves against learning objectives instead of achieving grades (Rissanen, Kuusisto, Tuominen & Tirri, 2019). • When celebrating success with students or colleagues, direct attention to the processes that led to the success (PERTS Mindset Kit, 2020).
Tasks and assessments
• Use pre-tests as a basis for comparison so students can see their learning progress (Dweck, 2010). • Assign open-ended projects or questions (Katz-Buonincontro, Hass & Friedman, 2017). • Reduce assessment that encourages comparison with others (Whittington, Rhind, Loads & Handel, 2017). • Allow students to be inspired by and learn from others' successes (O'Brien, Makar & Fielding-Wells, 2015), for example with poster displays, video or in-class presentations. • Encourage and showcase different ways to solve types of problems (Sun, 2015). • Give tentative grades that can be improved on through multiple opportunities for taking tests or submitting assignments (Sun, 2015). • Giving written feedback on assessments instead of grades (Masterson, 2020).
Community norms
• Encourage students to embrace challenges, to persist in the face of challenges, to see effort as the path to mastery, and to become comfortable learning from criticism (O'Brien et al., 2015).

- Equate challenging tasks to valuable learning experiences and easy-to-complete tasks as boring or as sub-steps towards larger goals (Dweck, 2010; Rissanen et al., 2019).
- Encourage lecturers and teachers to model learning from mistakes (Dweck, 2000).
- Teach lecturers, parents, other university staff and students how to react to success and failure in ways that promote growth mindsets (Haimovitz & Dweck, 2017).
- Have a personally influential person routinely make growth mindset declarations, such as, “You can do anything you put your mind to,” rather than “You are bright,” or “You are not a numbers person” (Heslin et al., 2019).

6.5. Comparing growth mindset enablers from literature with experiences of first-year engineering students

6.5.1. Methods and methodology

Three sources of data were gathered to address the research question, *What experiences that develop growth mindsets do first-year engineering students recall?* Firstly, a summary of experiences that promote growth mindsets was made through a literature search, summarised in Table 6.2. Experiences that involved in-depth mindset interventions such as learning about mindsets and advocating the benefits of growth mindsets to a peer (Aronson, Fried & Good, 2002) were omitted, since students’ exposure to such interventions was not expected in a South African context. Secondly, to establish a baseline assessment of mindsets that would help to contextualise this study with international studies, first-year engineering students (n = 64 from a group of 196 students) at a research-intensive South African university completed an online mindset questionnaire in their second semester of university. The eight-item mindset questionnaire was based on the original *Implicit theories of intelligence (general form)* scale by Dweck (2000) and modified according to De Castella and Byrne (2015) and Nelson, Gee and Hoegler (2016) to be personal and domain-specific by using ‘my mathematics ability’ rather than ‘intelligence’ in the scale items. The questionnaire items are listed in the appendix.

The third data source was from interviews. Students were asked during lectures by the researcher (who was not involved in the teaching of the course) to volunteer for interviews of up to 30 minutes. Seven students (four female, three male) volunteered and were interviewed in the last two weeks of the second semester. Students who had not completed the online questionnaire completed the questionnaire on paper before the interview. Interviews were semi-structured with questions designed to identify whether students recalled the mindset enabling experiences from their school or first-year university experience. Quotes relevant to the experiences in Table 6.2 were transcribed on a spreadsheet. A summary table (Table 6.4) relating experiences from Table 6.2 with the interview data from all seven students was compiled. Ethical clearance and permission to access students was obtained from the university before data collection commenced. No incentives for participation were offered.

6.5.2. Literature-sourced experiences that promote the development of growth mindsets

Table 6.2 summarises experiences suggested by published studies to promote the development of growth mindsets. The same experiences have been found in numerous other published studies, hence the references quoted are sample references that link an experience to the development of growth mindsets. The sample references are from six journal articles, two books, one book chapter and one conference paper.

The order of the experiences in Table 6.2 reflects findings from interviews done for this study with seven engineering students (discussed in the following section), with the most frequently reported experience at the top of the table.

Table 6.2: Experiences that promote the development of growth mindsets

	Experience	**Sample references**
1	Reflecting on personal achievements resulting from hard work.	Mercer & Ryan (2009) *Journal article*
2	Not feeling a need to prove oneself to others. / Not seeking approval from others. / Not prioritising approval from others.	Dweck (2006) *Book*
3	Using different strategies when encountering challenges.	Boaler (2015) *Book*

4	Making mistakes in a supportive learning environment where learning from mistakes is emphasised and valued.	Blackwell, Rodriguez & Guerra-Carrillo (2015) *Book chapter*
5	Wanting to improve ability more than demonstrate ability.	Dweck & Leggett (1988) *Journal article*
6	Being held to high standards.	Clark & Sousa (2018) *Journal article*
7	Learning the brain science about how learning happens.	Bettinger, Ludvigsen, Rege, Solli & Yeager (2018) *Journal article*
8	Being praised for effort (process) that leads to learning, more than praised for grades (product).	Kamins & Dweck (1999) *Journal article*
9	Hearing a role model or teacher tell their story of overcoming setbacks through hard work.	Lin-Siegler et al. (2016) *Journal article*
10	Reflecting on past experiences, noting the potential cost of holding a fixed mindset and value of holding a growth mindset.	Dringenberg, Shermadou & Betz (2018) *Conference proceedings*

6.5.3. Insights from survey responses

Responses to the eight-item mindset questionnaire results from first-year engineering students at a South African university are summarised in Table 6.3. For the 56 students who fully completed the questionnaire and provided consent for their results to be used for research, a Cronbach alpha coefficient was calculated as 0.77, which indicates that for this sample, the mindset scale is reliably measuring mindset (Taber, 2018).

Table 6.3: Classification of mindset according to weighted score from mindset questionnaire

Weighted mindset score	**8 to 16**	**17 to 24**	**25 to 31**	**32 to 39**	**40 to 48**
Classification	Strong fixed mindset	Moderate fixed mindset	Neutral mindset	Moderate growth mindset	Strong growth mindset
Number of students (Total: 56)	0	0	3	8	45
Percentage	0%	0%	5.4%	14.3%	80.4%

Using to the classification from Table 6.3, none of the 56 students were identified as having fixed mindsets, 5% had indeterminate or 'neutral' mindsets and 95% of the students had growth mindsets. The dominance of growth mindsets may be a result of three factors. Firstly, the students had been shown a 3-minute video on growth mindsets (Khan Academy, 2014) before they took the survey. Secondly, the lecturer had a teaching approach that promoted growth mindsets. Thirdly, there may be selection bias in the sample of students who voluntarily completed the survey, since fixed mindset students may be unwilling to expose any weakness. The seven students who volunteered to be interviewed had scores from 40 to 47, indicating strong growth mindsets.

Table 6.4: Students' mindset scale scores and recall of growth mindset enabling experiences

Experience	Nosipho	Mandisa	Tshepang	Joe	Muscovado	Scott	Edward
1. Reflecting on personal achievements resulting from hard work.	Yes, seen how work leads to results.	Yes, sees struggle as something to overcome.	Yes, inspired by "what I've been through."	Yes, challenging Physics course in first semester.	Yes, but not in academics.	Yes, chemistry practical in first semester.	Yes, motivates others with stories of own struggles.
2. Not feeling a need to prove oneself to others.	Used to in school, but now "I don't care what anyone else thinks of me."	Yes, does not feel the need to prove herself to others.	Yes	Yes, focus on "myself," family "don't push."	Yes, wanting to do well for self not others.	Yes, tries to remain humble.	Yes
3. Using different strategies when encountering challenges.	Yes, "You can't keep doing the same thing and expect different results."	Yes, "I am learning, picking up new habits."	Yes, at university.	Yes, "I would take a long time, because I would try different things."	Yes, "people wouldn't go into engineering if they did badly and gave up."	Yes, teacher would get students to explain to small groups.	Yes, when teaching peers in home language.
4. Making mistakes in a supportive learning environment where learning from mistakes is emphasised and valued.	Yes, "I'm used to challenges. It wouldn't be fun if things were just easy."	Yes, "In a small group it's fine." Considers if mistakes made were careless or conceptual.	Somewhat, "It ... depends on the audience ... how they take mistakes."	Somewhat, "I'll rather decrease expectations."	Yes, "You can't get good or better if you don't do badly and try again."	Yes, when teaching peers.	Yes, "If I made a mistake and there's people, I'll be like, 'I made a mistake here' and move on."

5. Wanting to improve ability more than demonstrate ability.	Somewhat, “It used to annoy me if a class was difficult. Now I see it as a positive thing.”	Yes, when praised, felt that she could do better.	Yes, sets goals to work harder than for previous tests. Aims for 80%.	Somewhat, first goal "don't fail", wants 75% average by year end.	Yes, continuous trying should lead to getting better. "You have to compete against yourself"	Somewhat, aims for 100%, advised not to settle for less.	Yes, " I need to know where I made my mistakes, so I don't repeat those mistakes again."
6. Being held to high standards.	Somewhat. At school, cared about what others thought.	Somewhat. Felt pressure not to fall behind peers.	Yes, feeling that praise was undeserved, "I can do much better than this."	Yes, a friend asked how he got to be first and copied his actions.	Yes, by a new art teacher who gave lower marks.	Yes, views tests as starting with 100% and losing marks from mistakes.	Somewhat. Not wanting to embarrass self in front of others.
7. Learning the brain science about how learning happens.	No	No	Yes, in a nationwide after-school programme.	Yes, recently read *A mind for numbers (Oakley, 2014)*.	Yes, from school.	Yes, recently read *A mind for numbers (Oakley, 2014)*.	Yes, in a nationwide after-school programme.
8. Being praised for effort (process) that leads to learning more than praised for marks (product).	No, but see grades as not more motivating than a desire to work.	No	No, but "back at home they don't really praise me 'cos they know … how much work I put in."	No, "People praise for the marks. They don't care about how you got there."	No	Somewhat, called Einstein, the mathematician but peers "liked me for what I knew."	Yes, praised for teaching peers.

9. Hearing a role model or teacher tell their story of overcoming setbacks through hard work.	No	No	No	No	No	No, "not really telling of their experiences."	No, "Most of the colleagues that I'm looking up to, ...they [make] everything seem easy"
10. Reflecting on past experiences, noting the potential cost of holding a fixed mindset and value of holding a growth mindset.	No	No	No	No	No	No	No
Mindset Score	**43**	**43**	**40**	**47**	**46**	**44**	**45**

6.5.4. Insights from interviews

The first six growth mindset enabling experiences in Table 6.2 matched, at least somewhat, the experiences of all seven interviewed students. Table 6.4 shows that there were three experiences common to all seven interviewed students:

- *Reflecting on personal achievements resulting from hard work;*
- *Not feeling a need to prove oneself to others; and*
- *Using a different strategy when encountering challenges;*

All students also had some experience of:

- *Making mistakes in a supportive learning environment where learning from mistakes is emphasised and valued;*
- *Wanting to improve ability more than demonstrate ability; and*
- *Being held to high standards.*

On the experience of *reflecting on personal achievement resulting from hard work,* Joe and Nosipho spoke of struggle and effort as an essential part of achieving results from learning. Joe recalled struggling in a physics course:

> *… I prefer struggle. It's better for learning. I didn't understand that last semester in physics. It was like, 'I feel like he's punishing us.'… Now that I'm out of it, I think, if every module could be like that, it would be good. [Joe]*

Nosipho saw the need for herself to apply effort but perhaps believed that there are 'naturally smart' people who might not need effort: "I feel like, at this point, I'm not just naturally smart, I have to put in effort to get the results." In high school, Edward would explain mathematics to his peers: "When there was no teacher, I was standing there helping others …" and he noticed that, "The more I explain the concept, the more I kind of grab it." He would motivate peers by sharing stories of how he experienced and overcame academic struggles.

For most of the interviewed students, high school peers were more influential than teachers in pushing them to *hold to high standards*. While this is an experience that promotes growth mindsets, the reasons given by three students indicated more of a fixed mindset reason due to a concern about what others thought of them, leading to a classification of 'somewhat' on Table 6.4. Nosipho cared about what others thought of her in relation to her academic achievements, Mandisa did not want to fall behind peers and Edward did not want to be embarrassed in front of peers due to neglecting work. While no student felt they needed to *prove themselves*, the influence of peers may have inspired a higher level of performance. For Nosipho, peer influence in maintaining high marks was missing at university: “In high school it mattered what others thought of me … now I don’t care what anyone else thinks of me, honestly.” Advice from a tutor while in high school helped Joe not to prove himself by seeking approval from others.

> *A physics tutor discouraged me from taking praise. At the beginning of our sessions he would be like, 'Don't be happy when people say you're smart. What is smart?' Ever since then … people praise me, but it never got to my head. [Joe]*

All students showed the *use of a different strategy when encountering challenges.* Regarding advice on sleeping regular hours, Nosipho reflected, “I was like, ‘It’s not going to work for me ‘cos I’ve never been that person.’ I realise now that … you can’t keep doing the same thing and expect different results.” Muscovado saw a relationship between being the flexibility of strategy choice when encountering challenges and the nature of the engineering profession: "The role [of an engineer] keeps developing therefore I need to keep moving with it. … People wouldn't go into engineering if they did badly and gave up."

When investigating students’ experiences of *making mistakes in a supportive learning environment where learning from mistakes is emphasised and valued*, most students expressed that having an audience for your mistakes is not desirable, but it happens often. They recognised that working through mistakes leads to more learning. Joe commented, “I don’t think anyone wants to make a mistake in front of other people.” Joe preferred for people to think of him as the least able in a group so that they expect him to make mistakes: “I’ll rather decrease expectations.” Tshepang noted that the experience of making mistakes can be positive or negative: "It also depends on the audience, and how they are engaged, how they take mistakes and all of that." Scott was comfortable with making mistakes when peer-teaching:

> *… back in school I would teach my fellow classmates, and sometimes I did make mistakes, ja, I did make mistakes and someone would point it out, 'Sorry, you made a mistake there', and I'd be, 'Oh, ja, ja, it is supposed to be*

> *this, thank you' ... I think it's best we accept our mistakes. Just move on. For me it was never a big deal. [Scott]*

The growth mindset experience of *wanting to improve ability more than wanting to demonstrate ability* was evident in Mandisa who, when praised for doing well academically, recalled: "I always felt that I could do better," although to 'do better' may have referred to improving grades rather than ability. Nosipho implied that she cared more for improving ability rather than easily scoring high grades: "It used to annoy me if a class was difficult. Now I see it as a positive thing." Scott's response showed that *wanting to improve ability more than wanting to demonstrate ability* may not clearly promote growth mindsets, if the fixed mindset trait of preferring to 'demonstrating ability' is extended to more than grades. Scott's stated: "I think the ultimate goal is for me to be able to understand and to be able to explain it to other people." Therefore, Scott would be demonstrating ability by improving his ability to explain to others, rather than demonstrating ability just with grades. Scott was also advised by a teacher to aim for 100% in tests.

The experience of *learning the brain science about how learning happens* is perhaps the most common mindset intervention (e.g. Blackwell, Trzesniewski & Dweck, 2007), however it was not an experience common to the seven growth mindset students. Three students had this experience while at school; two students read a book explaining how learning happens from a brain science perspective (Oakley, 2014/2007) in their first year at university; and two students did not have this experience, as noticed in Muscovado's quote, "I know a bit ... I've been wanting to learn more."

Three experiences were either absent from students' experiences or could be seen as minimally influential in the development of growth mindsets as they were not recalled when questioned about them. These experiences are:

- *Seeing the usefulness of the study topic;*
- *Being praised for effort (process) that leads to learning more than praised for grades (product);*
- *Hearing a role model or teacher tell their story of overcoming setbacks through hard work; and*
- *Reflecting on past experiences, noting the potential cost of holding a fixed mindset and value of holding a growth mindset.*

Students said they were interested in how the mathematics topics studied at school could be relevant to their lives but at school they were content to study abstract topics as part of the ‘package’ that needed to be mastered.

> *Ja, they don't teach us, like, you're going to apply this in world sometime ... Most students are like, 'Maths, I don't use this anywhere in my life.' Even though I was performing I can tell you there were instances I didn't think I would apply this in my life, I was just passing.* *[Joe]*

> *I feel like I've always had this question inside me, 'Why are you learning this, why are you learning this?' But at the time getting good marks is all that is working for you.* *[Scott]*

At university, more links between engineering, mathematics and physics were made, which students appreciated. Scott recalled how in university mathematics, “… my lecturer would start every section with a summary and say where this can be used in your engineering career.”

As in many countries, entry to university in South African depends on high academic achievement at school. The common experience of *praise for grades rather than praise for effort* reflects this emphasis by teachers, family and peers, although Tshepang added that "back at home they don't really praise me 'cos they know … how much work I put in." Although most praise experiences centered on grades, the interviewed students appeared to be minimally influenced by praise. Joe’s comment, “People praise for the marks. They don't care about how you got there," suggests that praise for grades has ceased to be held in high regard by growth mindset students. Muscovado said, "... you got praised by your friends, 'Wow, that's a really great mark'... My class was not that competitive, but you knew people's places. You just wanted to beat everyone.”

Interestingly, the recall of *hearing a role model or teacher tell their story of overcoming setbacks through hard* work – what Anderson (2017) calls a ‘backstory’ of hard work leading to success – was absent from all interviews. Edward commented,

> *Most of the colleagues that I'm looking up to, ... I never got to that stage with someone where they say, 'I once came across this challenge and it was hard for me.' … they have this thing of making everything seem easy.*

Towards the end of an interview, one student suddenly recounted a teacher's story of achieving 100% for high school mathematics and 26% for their first university mathematics test. At the time the story was dismissed by the class: "We didn't think that could be us." This example suggests that it is possible that students actually had been told stories of hard work overcoming academic setbacks, but as they were high achievers, the stories were not significant to them and therefore were not recalled in the interviews. Gilbert (2005/2007) explains that our feelings of being unique individuals keeps us from learning from others' experiences. Backstories may need to be timed to match periods of struggle for them to be experienced as significant.

After saying that they did not recall someone like a teacher telling their story of hard work leading to overcoming an academic setback, most of the students then spontaneously spoke of a time when they *themselves* had worked harder following low performance, often with encouragement from a teacher or mentor, and how they saw how their hard work led to improved performance. Personal experience of hard work leading to success seems to be common to engineering students assessed to have growth mindsets.

None of the students had *reflected on past experiences, noting the potential cost of holding a fixed mindset and value of holding a growth mindset.* This experience, like many others used in growth mindset interventions and not included in Table 6.2, relies on students first understanding mindset theory. The interviewed students had not previously been part of any growth mindset interventions. Reflections in such interventions have included journal entries to reflection prompts following reading chapters of Dweck's (2006) book *Mindset* (Dringenberg & Kramer, 2019), writing advice to incoming students based on personal experiences (Broda et al., 2018) or writing about a time they strengthened their neural connections in mathematics (Hoang, 2018). Such reflections appear to need targeted interventions to be experienced.

6.6. Conclusion

There is ample research evidence that growth mindsets benefit students and society. However, developing growth mindsets is not straightforward. Theoretical reasons why mindset interventions might fail have been presented. The five-stage model of behaviour change (Prochaska & DiClemente, 1983) suggests that interventions can have uneven effects when participants are at different change-stages, and that longer time may be needed before the effects of an intervention are seen. Social psychology theories suggest ways to make interventions memorable, credible, normal, and important (Bettinger et al., 2018), and therefore more likely to be effective.

Growth mindset messages aimed at students have been shown to work better if they appeal to social norms, give recipients a sense of autonomy and use self-persuasion, for example, by persuading future students of the benefits of growth mindsets through writing or making a video (Tough, 2014; Yeager, Walton & Cohen, 2013). The same principles can also guide growth mindset interventions aimed at developing growth mindsets by influencing the members of students' social communities. For example, students could be asked to share links to online interventions through social media platforms and to create or pass on memes that use humour to reinforce growth mindset perspectives.

The model of mindsets as *dispositional* (reflecting fundamentally who you are and what you can do) or *deliberate* (able to be invoked) (Heslin et al., 2019) provides another explanation for why growth mindset interventions have had mixed effects on academic outcomes (Sisk et al., 2018). Interventions may only be affecting deliberate rather than dispositional mindsets and therefore only have a temporary effect on mindsets. Dispositional mindsets are likely to be slower to shift as they have been developed and reinforced over years. Furthermore, shifts from fixed to growth mindsets may be reversed if the social environment reinforces dispositional fixed mindsets.

The importance of the learning environment in promoting and sustaining shifts towards growth mindsets has been argued (Yeager et al., 2019). Since dispositional mindsets have been developed over years, they are likely to need continuous reinforcement by significant people in the learning environment in order to shift. However, lecturers and teachers may unintentionally perpetuate fixed mindsets (Campbell, Craig & Collier-Reed, 2020). For these reasons, interventions that only target students and do not address features in the broader social space of the learning environment will yield limited results, unless the environment is already supportive of growth mindsets.

Costa and Faria (2018) suggest that a fixed mindset focus on performance goals (such as grades and merit awards) can help students to adapt and achieve in an environment where competitive achievement is the most important factor for future success. Such environments raise a dilemma for educators committed to helping students succeed.

Achieving performance goals can help students to win opportunities such as bursaries, jobs and selection for further studies. However, focussing on achieving higher grades than peers is associated with less learning and more mental health problems (Schleider, Abel & Weisz, 2015). If students are invested in a system that supports a fixed mindset, they may not want to 'rock the boat' even if they recognise the limitations of the system.

While it has been argued that the learning environment should support growth mindset interventions, institutions can be resistant to change (Kloot, 2009). However, a lack of institutional support should not cause individuals to dismiss all interventions to develop growth mindsets. Social psychological interventions in educational settings can have a (reduced) impact without changing anything in the environment, by making small changes to students' perceptions of how they think about themselves and others, which reduces the effects of perceived threats in the environment (Spitzer & Aronson, 2015). When growth mindsets are not yet widely understood or held by most community members, educators may be the most significant reinforcers of growth mindsets.

The development of mindset assessment instruments that can separate dispositional mindsets from deliberate mindsets is recommended for future studies. Such instruments may involve variations of Likert-type scales together with interviews and observations, as recommended by Safrudiannur and Rott (2019). Validation studies of different mindset scales triangulated with interviews and observations of behaviour for the target population would increase the reliability of mindset measures.

Ideally, growth mindsets should be one part of an integrated, institution-wide framework to improve student success that includes other social psychological factors, such as belonging, self-efficacy, grit, goal-setting, and overcoming anxiety (Beltran, 2018; Fong et al., 2017). Further studies to understand the various effects of mindsets on students, particularly in higher education, are recommended (Bazelais et al., 2018).

Appendix

Mindset Questionnaire items based on De Castella and Byrne's (2015) self-theory adaptation of Dweck's (2000) original *Implicit theories of intelligence (general scale)*, with 'intelligence' replaced by 'mathematical ability.'

1. Regardless of my current mathematics ability level, I think I have the capacity to change it quite a bit. (*)

2. I can learn new things, but I don't have the ability to change my basic mathematics ability.
3. With enough time and effort, I think I could significantly improve my mathematics ability. (*)
4. My mathematics ability is something about me that I personally can't change very much.
5. I believe I can always substantially improve on my mathematics ability. (*)
6. To be honest, I don't think I can really change how able in mathematics I am.
7. I don’t think I personally can do much to increase my mathematics ability.
8. I believe I have the ability to change my basic mathematics ability level considerably over time. (*)

Note: items marked with (*) form the growth mindset sub-scale and need reverse scoring.

---------------------------- End of journal article ----------------------------

6.7. Reflection

To set the scene, this chapter started by drawing on social psychology theories to explain the shortcomings with mindset interventions and the assessment of mindsets. Next, a summary of literature-sourced experiences that promote the development of growth mindsets was compared with interview data from engineering students in which they recalled the experiences occurring (or not) in their past. Finally, conclusions from the data analysis provided support the claim that learning environments can influence the outcomes of the growth mindset interventions. Examples of how learning environments can support the development of growth mindsets were summarised from literature under the headings: perceptions of goals; tasks and assessments; and community norms.

The final chapter summarises the contribution of the entire thesis.

Chapter 7: Final reflection

In this thesis I have drawn on mindset theory (Dweck, 2006), learning theories (behaviourism, constructivism, communities of practice and connectivism), the five-stage model of behaviour change (Prochaska & DiClemente, 1983) and the dual-model of mindsets as *dispositional* and *deliberate* (Heslin et al., 2019) to support my central argument that growth mindset interventions need to focus on developing mindsets in learning environments and not just in individuals. The journey to this conclusion started with a theoretical framework linking mindsets to learning theories (chapter 2), progressed with a literature review on growth mindset interventions for engineering students (chapter 3), explored a tutoring project as an intervention platform (chapter 4), advanced with an in-depth study of mindset assessment (chapter 5), pointed to literature-sourced examples of how learning environments can support the development of growth mindsets (chapter 6) and concluded with a comparison of how growth mindset enablers from literature relate to the experiences of first-year engineering students (chapter 6).

By analysing six behaviours characteristic of growth mindsets and fixed mindsets – challenges, persistence, effort, praise, success of others and learning goals – in relation to the four learning theories of behaviourism, constructivism, communities of practice and connectivism, I showed how educators could inadvertently be sending fixed mindset messages. This is an important result because students with fixed mindset are more vulnerable to unhelpful academic behaviour (such as not seeking help, avoiding challenging problems) that leads to less learning and a greater risk of dropout from demanding degrees such as engineering.

I have systematically reviewed 642 journal articles, conference papers and PhD theses in 12 databases of engineering, education and psychology literature for mindset interventions involving engineering students and thoroughly analysed the 15 studies that met the inclusion criteria. The literature search found that studies were predominantly based in the United States of America, lasted one or two semesters, and involved first-year students. There was noteworthy variation in the number of participants (8 to 7686), interventions (5 substantively different types over 15 studies), mindset scales used to assess mindsets (5 variations in the number of mindset scale items, 3 variations in the number of Likert response options) and results (5 effective, 5 inconclusive, 5 'not effective' studies). I found that the most common intervention used in 10 of the 15 included studies was sharing mindset ideas through online tutorials, lectures or videos paired with discussion or reflective writing, and that this type of intervention was effective for large studies with high female participation (n = 486, 61% female and n = 426, 79% female). I suggested that future studies could explore how to find subtle ways to target interventions at students who might benefit the most from them, and whether growth mindset environments could help to attract and retain female engineering students.

I planned an intervention in which volunteer tutors would be sent mindset ideas on a social media platform to reword and share with tutees. Weak group functioning led to the iterative development of design-based research principles for establishing tutoring groups in a context with little or no face-to-face contact between tutor and tutee. It emerged that this intervention would have limited value since, according to Dweck's mindset scale, the tutors already had strong growth mindsets. Compared to other studies involving engineering students, where 15-21% of students had fixed mindsets, the paucity of fixed mindsets among engineering students (7% of 265 students) in my study was unexpected. Focus group meetings with tutors suggested that they held a wider range of mindset beliefs than their mindset scale responses showed.

Interviews with 16 students and a close-up analysis of two representative students showed that students who were classified by the mindset scale as having growth mindsets also had some fixed mindset characteristics, and that even without a targeted intervention, mindsets shifted slightly towards growth mindsets over the first year at university. Insights from the interviews with students led me to argue that developing growth mindsets in students will have limited impact in an unsupportive environment where, for example, assessment is not at the right level and students do not understand the expectations, or how to respond when assessed as underperforming. While the mindset scales may give a quick way to assess mindsets, a mindset score does not capture the range of mindset beliefs held by students. Students may have the same mindset score and yet interviews may show that they hold qualitatively different mindset beliefs.

I discussed limitations of mindset interventions and found support from social psychology research for claiming that:

- Interventions must be implemented so that they suit the context of the educational environment;
- Growth mindset messages will be more effective if perceived as *memorable*, *credible*, *normal*, and *important*;
- Short-term mindset interventions may appear to be less effective than theoretically expected because participants are at different stages of behaviour change; and
- Interventions that target a *deliberate* growth mindset may have short-lived effects. To shift *dispositional* mindsets, more reinforcement of growth mindsets may be required, for example through repeated messages from influential people such as teachers, professors or parents.

Reasons why growth mindset assessment may give distorted results were suggested, notably:

- The trustworthiness of students' responses can be brought into question through
    - the timing of mindset assessment; and
    - a mismatch between students' honest answers to surveys and their underlying beliefs;
- Mindset scales force an unrealistic separation of fixed mindset and growth mindset beliefs.

I proceeded to explore how students developed growth mindset characteristics. I identified growth mindset enabling experiences from literature and compared the findings with interview responses from seven first-year engineering students. Three of the ten identified experiences were common to all interviewed students:

- *Reflecting on personal achievements resulting from hard work;*
- *Not feeling a need to prove oneself to others; and*
- *Using different strategies when encountering challenges.*

A further three experiences were experienced to some extent by all students:

- *Making mistakes in a supportive learning environment where learning from mistakes is emphasised and valued;*
- *Wanting to improve ability more than demonstrate ability; and*
- *Being held to high standards.*

The experience of *learning the brain science about how learning happens* was absent from the experiences of four of the seven interviewed students, and three experiences were either not part of students' experiences or did not make a strong enough impression to be recalled by students:

- *Being praised for effort (process) that leads to learning more than praised for grades (product);*
- *Hearing a role model or teacher tell their story of overcoming setbacks through hard work*; and
- *Reflecting on past experiences, noting the potential cost of holding a fixed mindset and value of holding a growth mindset.*

Finally, I suggested that the comparison of growth mindset enabling experiences from literature with students' experiences indicated patterns that could guide the design of future growth mindset interventions for university students. The theoretical contributions of this study apply more broadly than to only engineering students at a South African university.

Since many engineering students have a history of high mathematics achievement and were distinguished from school classmates on the basis of high academic achievement, I initially postulated that first-year engineering students may be at risk of holding fixed mindsets due to being identified as more talented than their peers. However, responses to mindset scales by first-year engineering students at a South African university were overwhelmingly indicative of growth mindsets. The in-depth investigation into the mindsets of two representative engineering students showed that students can hold both fixed and growth mindset beliefs simultaneously and suggested that further research into developing mindset assessment tools particular to the assessed group of students is needed.

Further research can explore the possibility that the South African school system develops a high level of compliance in students and an ability to 'suss out' how to 'play the system' to maximise high assessment by authority figures. If this is the case, the desire to strategise how to achieve optimal test results may spill over to mindset assessments, so that students who discern that a lecturer or researcher favours growth mindsets may respond to the mindset assessment in a way that indicates a stronger growth mindset than might be found if students felt that a fixed mindset was the 'right answer.'

The central research question of this thesis,

> *How can growth mindsets be developed in engineering students?*

can be answered,

> *By creating learning environments that support and sustain growth mindset beliefs and behaviours.*

I conclude that developing growth mindsets in students is unlikely to result in changes to student success unless students experience reinforcement of growth mindset beliefs in the lecturers, peers and structures that most strongly influence their learning environments.

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